MONTHLY 10/-

BUCKNELL UNIVERSITY LIBRARY
SEP 3 1952
LEWISBURG, PA.

THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY

CONTENTS **AUGUST 1952**

SECRETARY'S NEWS LETTER AND NOTICES

THE LATE COLONEL W. C. DEVEREUX, C.B.E., FELLOW

THE SPACING OF AIRCRAFT UNDER HIGH DENSITY APPROACH CONDITIONS
E. A. Whiteley, D.F.C., B.A., A.F.R.Ae.S.

SOME NOTES ON AIRCRAFT OVERHAUL AND MAINTENANCE
C. H. Jackson, B.Sc., A.F.R.Ae.S.

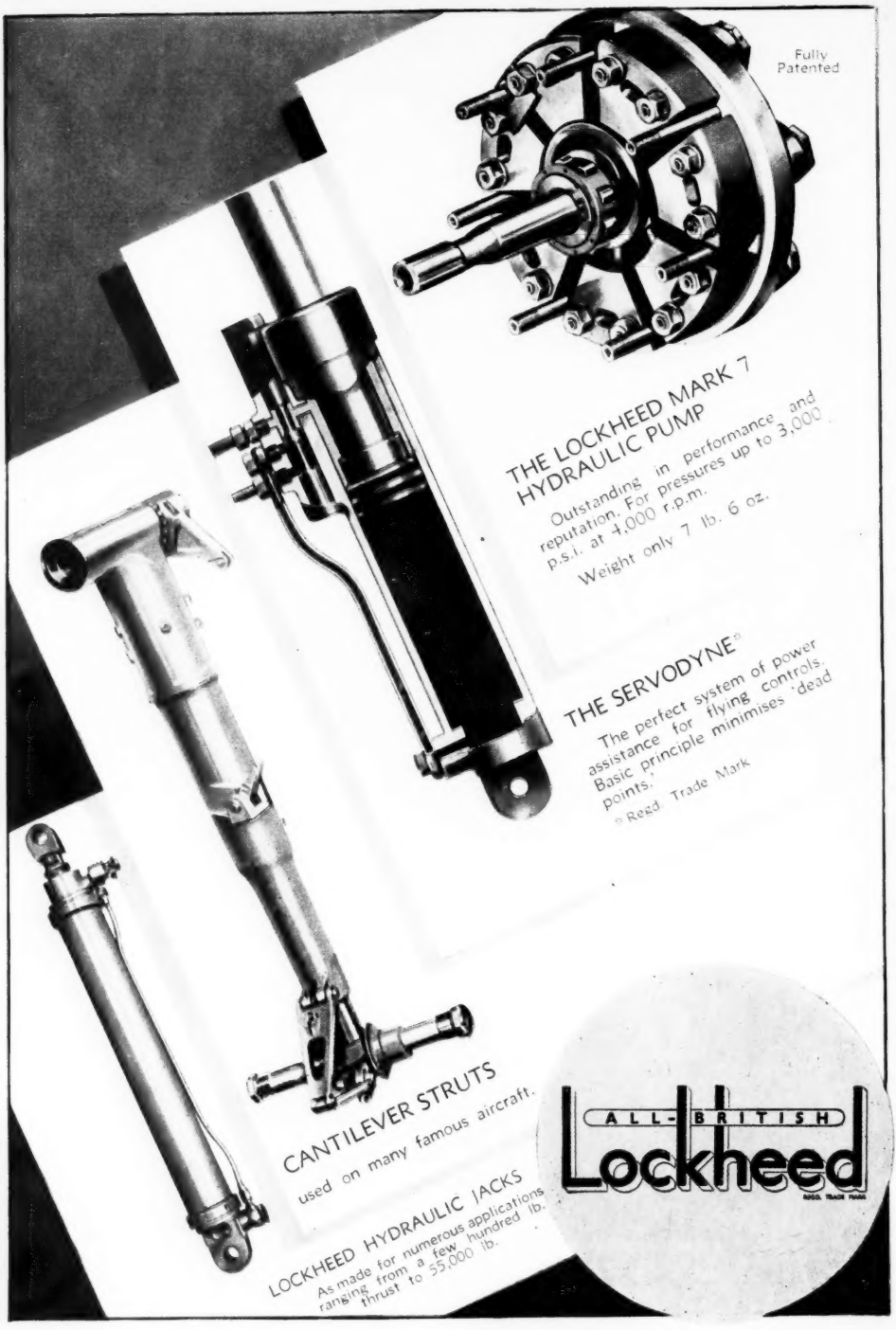
THE 1952 GARDEN PARTY

REVIEWS

ADDITIONS TO THE LIBRARY

LONDON

ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, W.1


Fully Patented
THE LOCKHEED MARK 7 HYDRAULIC PUMP
Outstanding in performance and reputation. For pressures up to 3,000 p.s.i. at 4,000 r.p.m.
Weight only 7 lb. 6 oz.
THE SERVODYNE*
The perfect system of power assistance for flying controls. Basic principle minimises 'dead points.'
* Regd. Trade Mark
CANTILEVER STRUTS
used on many famous aircraft.
LOCKHEED HYDRAULIC JACKS
As made for numerous applications ranging from a few hundred lb. thrust to 55,000 lb.
ALL-BRITISH
Lockheed

AUTOMOTIVE PRODUCTS COMPANY LTD., LEAMINGTON SPA

Secretary's News Letter

AUGUST 1952

THE Garden Party was held on 15th June, and I think it was quite successful. However I was very disappointed at the attendance, which was several hundreds less than last year. I cannot account satisfactorily for this, but I hope that it is only temporary.

Elsewhere in this Journal acknowledgments and thanks have been given to all those who helped in the organisation of the Garden Party. I wish to add my personal thanks to everybody, especially to Group Captain Slade and his secretary, Miss Somerville. They added a further verse to Ruth: "and your worries shall be my worries."

The de Havilland Old Boys' Association, in conjunction with the London Flying Club, held a dance at Hatfield on Friday 27th June. It was a very pleasant summer's evening; if you didn't want to dance you could talk, or even swim, for the pool was open to visitors. "Fairy Lights" illuminated the grounds; there were two moons in the sky, for the organisers were making sure that the romantic adjuncts were not missing. Possibly the best turn in the cabaret was the appearance of a noisy and fearsome prophetic jet car. Congratulations to the Secretary for a very enjoyable evening.

The Northern Heights Gala was held at Langley Airfield on Sunday 29th June, and, at the invitation of the President, Dr. A. P. Thurston, I appeared in the role of paterfamilias. The children (and their parents) enjoyed the flying, very adequately complemented by the hospitality of Hawker Aircraft Ltd.

This issue of the JOURNAL is numbered 500, and that is an achievement in which the Society can take much pride. It was first published in January 1897. Lest my arithmetic be questioned, until January 1918 the JOURNAL was published quarterly. The History of the Journal was written by Captain J. L. Pritchard and appeared in the January issue, 1945, and it was from this that I culled my facts.

In a previous News Letter I mentioned the historical aviation film which the Society was sponsoring and asked for details of any films in the possession of members. I have had a fair response, but I feel sure that there are many films still to be rediscovered.

This year the Annual Meeting of the British Association for the Advancement of Science is being held in Belfast. The President of the Engineering Section is Sir Ben Lockspeiser, K.C.B., F.R.S., F.R.Ae.S., and the title of his presidential address is "Progress in Aeronautical Science and Engineering." This will be given on Friday 5th September.

On 8th September Mr. David Keith-Lucas, F.R.Ae.S., will give a paper on "The Shape of Wings to Come."

There are two more papers of aeronautical interest—"The Biology of Flying" and "Servo-Mechanisms in Aircraft and Ships."

Unfortunately the date of the meeting—3rd-10th September—clashes with the S.B.A.C. Show week but it may be possible for interested members to attend the latter part of the meeting.

The "Discussions" on the papers read at Brighton during the Third Anglo-American Conference in 1951 are now available to Delegates. These are complementary to the papers, and complete the Proceedings. Three of the authors have added additional information to their papers.

A. M. Ballantyne

Secretary

NOTICES

CONTENTS OF THE AUGUST JOURNAL

Secretary's News Letter and Notices

The Late Colonel W. C Devereux, C.B.E., *Fellow.*

The Spacing of Aircraft Under High Density Approach Conditions, E. A. Whiteley, D.F.C., B.A., A.F.R.Ae.S.

Some Notes on Aircraft Overhaul and Maintenance, C. H. Jackson, B.Sc., A.F.R.Ae.S.

The 1952 Garden Party.

Reviews. Additions to the Library.

(An annual sum of £250 is available for premium awards for papers published in the Journal. These premium awards are usually 15 guineas each. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics.)

ASSOCIATE FELLOWSHIP EXAMINATION

Home entries for the December 1952 Associate Fellowship Examination should be received by the Secretary not later than 31st August 1952. The lists for entries outside the United Kingdom have been closed.

BIRTHDAY HONOURS

The following is an addition to the list published last month of members of the Society who were honoured by the Queen on the occasion of Her Majesty's Birthday:—

O.B.E.

Wing Commander C. A. Pike, A.F.C., *Associate Fellow.*
G. W. Stallibrass, *Associate.*

M.B.E.

G. A. Champniss, *Associate.*
L. C. Skinner, *Associate Fellow.*
A. W. Watkins, *Associate Fellow.*

HONOURS AWARDED TO MEMBERS

The Gold Albert Medal of the Royal Society of Arts for 1952 has been awarded to Air Commodore Sir Frank Whittle, K.B.E., C.B., M.A., F.R.S., *Fellow*, "for the development of the continuous-combustion gas turbine and jet propulsion." The Albert Medal, which is the highest award of the Royal Society of Arts, was instituted in 1864.

Mr. Arthur Hillier, O.B.E., J.P., *Associate Fellow*, Chairman of the Sperry Gyroscope Co., has been appointed an Officier de la Légion d'Honneur "in recognition of the contribution which he has made to French aviation since the end of the First World War."

NEWS OF MEMBERS

Many of his friends will be interested to hear that Dr. J. C. Hunsaker, *Honorary Fellow*, is retiring from the Professorship of Aeronautical Engineering at the Massachusetts Institute of Technology. Dr. Hunsaker has been connected with the Massachusetts Institute of Technology since 1912. He will be in London from 17th-24th September and correspondence can be sent to him, care of the Society.

Mr. H. Burroughes, *Fellow*, Deputy Managing Director of Hawker Siddeley Group Ltd., has been elected President of the Society of British Aircraft Constructors Ltd. for 1952-53, and Mr. J. J. Parkes, *Associate Fellow*, Chairman and Managing Director of Alvis Ltd., has been elected Vice-President. Sir Frederick Handley Page, C.B.E., *Honorary Fellow*, has been re-elected Honorary Treasurer.

DIARY

LONDON.

October 2nd.

EIGHTH BRITISH COMMONWEALTH AND EMPIRE LECTURE. Maintaining Airworthiness in Operation. R. E. Hardingham, O.B.E., F.R.Ae.S. **Institution of Mechanical Engineers,** Storey's Gate, S.W.1, at 6 p.m. (Tea at 5.30).

BRANCHES.

September 10th.

Brough—Lecture by an American on Production Methods in the U.S.A. Electricity Showrooms, Ferensway, Hull. 7.30 p.m. Admission by ticket only.

September 16th.

Glasgow—Response Calculations. Professor W. J. Duncan. Royal Technical College. 7.30 p.m.

September 17th.

Coventry—Aerofoil Sections and their Derivation. E. T. B. Smith. The Wine Lodge. 7.30 p.m.

GRADUATES AND STUDENTS SECTION—VISITS

The following visits have been arranged by the Graduates and Students Section:—

20th September—B.O.A.C. Maintenance Area, London Airport. Meet at Main Passenger Gate (opposite Heathrow Cafe) at 2.30 p.m. Tea will be available.

25th October—All-day visit to the College of Aeronautics, Cranfield. A coach will be available and the fare will be approximately 10s. Further details will be announced later.

Members wishing to take part in these visits should apply to the Hon. Visits Secretary, C. B. Redgate, *Graduate*, 83 Wandle Road, Morden, Surrey.

MEMBERS' NEW APPOINTMENTS

F. T. BEVAN (*Associate Fellow*) has recently taken up a position as Design Engineer with Messrs. Lockheeds, of Burbank, California.

R. M. CLARKSON (*Fellow*), Assistant Chief Engineer and head of the Aerodynamics Department of the de Havilland Aircraft Co. Ltd., has been appointed a Director of the Company.

W. CLOSE (*Associate Fellow*), formerly a Project Design Draughtsman with A. V. Roe (Canada) Ltd., has been appointed a Research Mechanical Engineer at the Cornell Aeronautical Laboratory, Box 235, Buffalo, N.Y.

A. KENNETH CLYDE (*Associate Fellow*), formerly of the Ministry of Supply Instrument Research and Development Section, has been appointed Assistant Chief Engineer of Tiltman Langley Laboratories Limited.

C. Dykes (*Associate Fellow*), formerly with B.O.A.C., is now established as an Aeronautical Consultant.

G. E. FOWLER (*Graduate*), formerly of R.A.E. Farnborough, has joined the Design staff at the Government Aircraft Factories, Fishermans Bend, Melbourne.

D. L. HOLLIS WILLIAMS (*Fellow*) has been appointed Technical Director of Westland Aircraft Limited in place of A. DAVENPORT (*Fellow*). Mr. Davenport resigned his office as Technical Director, but retains his seat on the Board.

B. P. LAIGHT (*Associate Fellow*) has been appointed Chief Designer of Blackburn and General Aircraft Ltd. He was formerly Chief Aerodynamicist, Bristol Aeroplane Co. Ltd.

K. L. C. LEGG (*Associate Fellow*) has recently been appointed Assistant Designer (Structures) of Short Bros. & Harland Ltd., Belfast. He was formerly Assistant Chief Research Engineer.

H. ROBERTS (*Associate Fellow*) has been appointed Chief Aerodynamicist of the Fairey Aviation Co. Ltd.

W. M. WIDGERY (*Fellow*), a Director and formerly Chief Engineer of Normalair Ltd., has been appointed Technical Director of the Company.

ASSOCIATE FELLOWSHIP EXAMINATION RESULTS MAY 1952

The following were successful in the Associate Fellowship Examination held in May 1952:—

PART I

J. Allcroft, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; R. Ashford, Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

D. R. Barham, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; T. S. Beddoes, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; R. M. Blunt, Applied Mathematics, Properties of Matter, Heat, Light and Sound, Strength of Aircraft Materials and Theory of Structures I, Theory of Machines; D. G. A. Bridgnell, Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; D. R. Brodie, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Strength of Aircraft Materials and Theory of Structures I; W. R. Bryce, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

S. G. Corps, Properties of Matter, Heat, Light and Sound.

K. G. Draper, Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

P. J. Farmer, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; D. J. Frater, Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

R. A. Hacker, Applied Mathematics, Properties of Matter, Heat, Light and Sound, Strength of Aircraft Materials and Theory of Structures I, Theory of Machines; M. J. Harris, Applied Mathematics, Properties of Matter, Heat, Light and Sound, Strength of Aircraft Materials and Theory of Structures I, Theory of Machines.

J. A. Jehin, Applied Mathematics, Magnetism and Electricity and Electronics, Aerodynamics I, Theory of Prime Movers and Fuels.

I. H. Khan, Strength of Aircraft Materials and Theory of Structures I, Theory of Machines.

R. Lewis, Properties of Matter, Heat, Light and Sound.

D. W. Pickston, Properties of Matter, Heat, Light and Sound.

N. R. Reddy, Applied Mathematics, Theory of Machines; J. F. Richards, Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; A. G. Rogers, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; J. Rye, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

B. Singh, Theory of Machines; S. Singh, Strength of Aircraft Materials and Theory of Structures I, Theory of Machines.

D. H. Tipper, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

ABROAD—PART I

D. S. Carton (Karachi, Pakistan), Theory of Prime Movers and Fuels.

R. B. Lal (Allahabad, India), Aerodynamics I, Theory of Prime Movers and Fuels.

F/Lt. W. Raj (Madras, India), Properties of Matter, Heat, Light and Sound.

R. S. Skulsky (Wostok, Alberta, Canada), Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

PART II

A. D. Balmain, Aircraft Materials, Engineering Economics.

D. S. Bliss, Aerodynamics II; H. A. Buchholdt, Strength of Aircraft Materials and Theory of Structures II.

R. S. Dabbs, Strength of Aircraft Materials and Theory of Structures II; D. A. Drane, Strength of Aircraft Materials and Theory of Structures II.

L. J. Geering, Strength of Aircraft Materials and Theory of Structures II.
A. J. Heath, Aircraft Design.
B. T. Lewis, Aerodynamics II.
E. Mowforth, Engine Design.
G. A. C. Searle, Aerodynamics II; P. C. G. Stalkartt, Aircraft Design.
D. Wood, Engine Design.
J. C. Young, Aerodynamics II.

ABROAD—PART II

A. V. Ranga Rao (Madras, India), Aerodynamics II.
Cpl. T. W. Thomas, 577666 (R.A.F., Abyad, M.E.A.F.), Engine Design.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Charles Herbert Baldwin (*from Associate*)
Peter Ward Brown (*from Student*)
Edgar Allinson Bunt
John Gualbert Paul Callahan
Henry Cohen (*from Graduate*)
Leslie Crocker
Wallace Roy Cuff
Jerzy Dabrowski
Frederick James Edwards (*from Associate*)
James Charles Ellis
Myles Lonsdale Formby (*from Associate*)
Donald Ganson (*from Graduate*)
John Kenneth Gilbert (*from Graduate*)
Stuart William Greenwood (*from Graduate*)
George Francis Hugh Hemsley (*from Companion*)
John Laurence Horne (*from Graduate*)
John Wynford George James
Roff Taylor Jones (*from Graduate*)
Gordon Manns Lewis (*from Graduate*)
Anthony Christopher Loraine (*from Associate*)
James Cedric Morrall (*from Graduate*)
Denis Roland Murrin (*from Graduate*)
Noel Henry Nash (*ex Associate*)
Colin Charles Parsons (*from Graduate*)
Edwin Charles Witter Pearce (*from Associate*)
William Thomas Shipston Pearson
Maurice Sevik (*from Graduate*)
Thomas Derek Sills (*from Graduate*)
John Stack
Geoffrey Cowie Sugden (*from Graduate*)
Sidney Timmins
Harold Townley (*from Associate*)
James William Whitelegg

Associates

Nigel George Victor Anslow
Stewart Brumby Beevers
John Graham Cowley
Francis Cumberland
Ronald Leslie Devon
Alfred George Foster
Paul Henry Francis
Pierre Carl Gassin
Aubrey Henry Thomas Hancock
Robert Earl Hanley (*from Graduate*)
Herbert John Harvey
Edgar Heathcote
Malcolm Alexander Henderson
Leonard Cecil James
William Melville Lingham
Keith Alexander MacKenzie
Wallace Barclay Osborne
Hubert John Parker
Robert Norman Rowland
Donald Rought
Harold Roger Strange
Pierce Butler Talbot
Frederick Garnet Withall

Graduates

William Henry Barber (*from Student*)
Stanley Arthur Birch
Kenneth Ernest Farrance
Max Theodore Friedl
John Roland Gregory
Zbigniew Jawor (*from Student*)
William Kelsey

William Weir Lewis
Peter John Midgley
Leslie Frank Nicholls (*from Student*)
Raymond Nichols
Trevor Howard Powell
(*from Student*)
John Ireland Read
Earle Rhoades (*from Student*)
William Ronald Steedman
Brian Rodney Townsend
Ronald Thomas Upton
(*from Student*)
Gordon Harry Vosper
(*from Student*)

Students

Colin George Holdstock Abrahams
John Allcroft
George Graham Appleby
David Ronald Barham
Thomas Shelley Beddoes
Hans Anton Buchholdt
Patrick Edward Cunningham
Thomas Golding Letten Davis
David John Frater
John Parsons Holmes
Richard Charles Hotton
Stanley William Owen Ivermee
Leslaw Jerzy Jelonek
Brian Angus Fleming McLellan
Alan Payne
Albert Charles Pruden
Kenneth Owen Rowe
Harindra Kishore Singh
Robert Arthur Smith
Khursked Jivanji Taraporevala
Edward Peter Lloyd Windsor
Richmond Harcourt Wordsworth

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the gift of a number of small relics of aircraft of the 1914-18 War from W. A. Woodward, Esq.; the gift of books and JOURNALS from Lord Brabazon, *Fellow*, and N. A. Nicholas, Esq., *Fellow*, and the return of back numbers of the JOURNAL from S. F. Titt, Esq., *Associate*.

INCOME TAX

In response to numerous inquiries from members with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes.

Ref. H.R.S. 34/C.I. 4420/63.

Dear Sir,

Further to your interview with Mr. Stonely at this office on the 19th July, I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(*i*) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business on: or

(*ii*) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully, (Signed) GEO. WILCOCK,
Principal Inspector of Taxes.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the JOURNAL for the following month.

Wallace Charles Devereux, C.B.E. Fellow

1893 - 1952

WITH THE DEATH of Wallace Charles Devereux aviation has lost one of its most brilliant figures, and a host of people a great friend. Of all his personal characteristics, indeed, the one which stood out above all others was that of friendliness, for there was a readiness in his smile which belied the greatness of his mind. In aviation he was widely known for his work in the development of aluminium alloys, for his insistence on the importance of research, for his technical knowledge. Yet many will remember him for many other lesser, perhaps, but more important reasons. My own most vivid memory of him is that of one spring evening in 1941. I was talking to one or two friends in his house when Devereux came in the room, his eyes all lighted up, waving a copy of *The White Cliffs* by the American poet Alice Duer Miller, which had just been published.

"Listen to this," he cried, and he read those moving last few lines,

"I am American bred,
"I have seen much to hate here—much to forgive,
"But in a world where England is finished and dead,
"I do not wish to live."

The Aeroplane

And then he read line after line at random, chuckling with the pleasure of his new found discovery. I learnt afterwards that he had bought hundreds of copies to give away, so that others could share his delight. It was then that I learnt how well read he was, how his hail-fellow-well-met air, his *bon viveur* attitude towards life, hid an unusual mind, that of a man who felt deeply of spiritual things despite his realistic light material outlook. Once, afterwards, I sent him other verses, and he wrote back to tell me how he had wept reading them.

Devereux was a great friend of the Royal Aeronautical Society. Elected an Associate Fellow in 1933 and a Fellow four years later, he served on the Finance Committee for ten years and was its Chairman for seven. During this period he was one of the leading spirits in helping to raise the Endowment Fund, and to put the finances of the Society into sound shape. It was during this period, too, that he played a leading part in enabling the Society to acquire its present headquarters, in face of much discouragement. A man of great vision in all he did, his name will be high in the annals of the Society which claimed so much of his time and affection. He attended the dinner following the Wilbur Wright Memorial Lecture on 29th May and I was acutely aware of the abounding vigour and charm so soon to be lost to us all.

Born on 9th March 1893 he was educated at King Edward's Grammar School, Aston. His astonishing ability was revealed in the First World War when, in his early twenties, he became superintendent of National Aircraft Factory No. 1. Following the end of the war he became works manager at Peter Hookers where he began to realise the increasing value of light alloy forgings and castings. In 1927, with the backing of John Siddeley, he founded High Duty Alloys at Slough. From the beginning of his work at Slough he insisted on the vital importance of research and technical supervision at every stage of the development of the light alloys. The standards Devereux set were so high that he gained the confidence not only of industry in this country but in many countries on the Continent where he was a popular and well known figure.

Devereux believed in himself and his work with such sincerity that his reputation stood high wherever he went and he had access to factories which were normally not easy to enter. Following such a round of visits to aircraft factories in Germany in the late thirties with Sir Roy Fedden, himself a keen observer, the two sent in a report to the Government of the day which foretold an expansion for war on an almost unbelievable scale. Devereux made sure that his own works should be as capable as possible and in 1939 he acquired the most powerful power-hammer in Europe, and in twelve months doubled the output of his factories.

With the outbreak of war Devereux became Director at the Ministry of Aircraft Production to control light alloy forgings and castings, and in 1941 he became Controller of North American Aircraft Supplies, in which post he was responsible for the reception and assembly of American aircraft and engines.

Following the end of the war Devereux turned his attention to the possible use, on a much larger scale than had yet been the case, of light alloys. In 1945 he formed Almin Ltd., and in two or three years he had made it one of the leading companies in the structural uses of aluminium and its alloys. One of his widely publicised structures in aluminium was the Dome of Discovery, and another the now well known telescopic gangways at the Ocean Terminal, Southampton. The aluminium hangars at London Airport are due to his work. In the same year as he founded Almin Ltd., Devereux founded the Fulmer Research Institute which has already taken a high place in industrial research.

A man of great energy in many directions, Devereux found time to take up farming in his spare time. In this he was as thorough and as successful as he was in the aircraft world. The technique he used for improving the breed of light alloys he used for improving his breed of pigs and cattle. Research and control and records were part of his method so that he knew exactly not only how to get the best results but why he got them. He found time to hunt and became Master of the Old Berkeley Fox Hounds. He was very proud, too, when he became Hon. Colonel of 114th (County of London) Regiment, R.E.(T.A.). Made a C.B.E. in 1949, he was Vice-Chairman of the Royal Aero Club and a liveryman of the Worshipful Company of Coachmakers and Coach Harness Makers.

Wallace Charles Devereux was taken ill at Ascot on 22nd June and died the same day. For many reasons, in many ways, his work and his kindnesses, his energy and his ability, his affections and his enthusiasms, that amalgam of virtues and faults which made him so much liked and disliked, will remain in the minds and memories of all those who knew him even if it were only for a few passing hours, or for many years. For "Dev" was one of those who would not have wished to live where England is finished. For there was so much in him that *was* England.—J.L.P.

The Spacing of Aircraft Under High Density Approach Conditions

by

E. A. WHITELEY, D.F.C., B.A., A.F.R.Ae.S.

The 850th Lecture to be given before the Royal Aeronautical Society was delivered at the Institution of Civil Engineers, Great George Street, London, S.W.1, on 20th March 1952. Major G. P. Bulman, C.B.E., F.R.Ae.S. (Past President) presided and introduced the Lecturer, Group Captain E. A. Whiteley, D.F.C., B.A., A.F.R.Ae.S., Royal Air Force, who was attending the Joint Services Staff College and who, in addition to being a pilot, had qualified as an R.A.F. Engineering and Navigation Specialist and also held a British Civil Airline Pilot's Transport Licence and a Flight Navigator's Licence.

1. INTRODUCTION

1.1. SCOPE AND INTENT

The purpose of this paper is to examine some of the techniques and methods which may be employed to ensure safety separation between aircraft during the approach to an air terminal under high density traffic conditions in the period 1955-1965. While reference is made to altitude spacing—and its utilisation is assumed — attention is focused primarily on longitudinal and lateral spacing. The flow of aircraft is assumed to comprise many types with differing approach speeds, arriving from a variety of directions and with initial altitudes up to 35,000 ft.

No mention is made of departing aircraft because the consequences of delay are less likely to be serious than with arrivals. If landing rates can be accelerated, the runways automatically become available to a greater degree for departing aircraft.

Neither tangential nor convergent runways figure in any of the systems discussed nor are they proposed by the author; with parallel movements only it is not perhaps too difficult to integrate departing aircraft with those which overshoot.

1.2. GENERAL PHILOSOPHY

There are two features of many existing air traffic systems which should be eliminated insofar as possible. The first is the stacking of aircraft in the vicinity of terminals. The second is the practice of having large numbers of aircraft under close control, *i.e.* subject to a continuous flow of verbal directions from the ground; it is felt that the rôle of the terminal area control staff should be analogous perhaps to that of a kindly constabulary watching a stream of vehicles pass a series of *automatic* traffic lights, rather than a series of policemen beckoning cars *individually* at every intersection.

To minimise local stacking, random arrivals at the outer limits of the terminal zone must be converted into a somewhat more regular flow of arrivals at the track mesh point where the aircraft begin their final straight approach to touch-down. Between that point and the runway any remaining altitude separation must be given up. At the same time plan spacing must be refined to permit the greatest possible flow on to the aerodrome. The acceptance capacity must be considerably greater than the maximum hourly arrival rate.

1.3. OUTLINE

A number of assumptions are made and discussed in Section 2; this is followed by an outline of the essential elements of any system and the various phases of any approach. In this review a provisional decision is taken as to the length of the common straight track leading to the runway. Longitudinal spacing possibilities in a single stream along this uni-directional

Note: The views expressed in this paper are those of the author. They do not necessarily represent the policy of any Government Department or Service, British or American, with which he has been associated. The paper was completed in Australia in August 1951.

track are discussed in Section 4 on the basis of various flight techniques—specified air speeds, specified ground speed, specified distance from the aircraft ahead using air or ground radar measurements. These same techniques are further examined in Section 5 in relation to the preceding phase of the approach, namely the regulation of omni-directional descents to the track mesh point (including the turn).

In Section 6 attention is turned from longitudinal spacing to lateral spacing possibilities, *i.e.* the use of parallel streams from the track mesh point on to the airfield. Practical accomplishment in track keeping is reviewed and the possibility of exploiting this to multiply the flow of aircraft onto an aerodrome is discussed.

It is suggested that parallel approaches offer great possibilities, particularly in a period where there is a certain lack of international standardisation and a dearth of devices suitable for maintaining longitudinal spacing. It is also argued that in any case the problem is not one that can be left to the navigators and electronic engineers. If tight longitudinal spacing is to be our Mecca, the aircraft designer may well have to provide new methods of controlling aircraft forward speeds. If lateral spacing and parallel runways are to be exploited, there are implications in airport design and aircraft cross-wind landing characteristics which merit early study.

1.4. Terminology

Abbreviations

E.T.A.	Estimated time of arrival.
D.M.E.	Distance measuring equipment.
I.F.R.	Instrument flight rules.
C.A.V.U.	Ceiling and visibility unlimited.
G.C.A.	Ground controlled approach ("talk down" approach system).
A.G.C.A.	Automatic ground controlled approach.
P.A.R.	Precision approach radar, *i.e.* the portion of a G.C.A. system used for the final approach.
A.I.	Air interception equipment (in the U.S.A., air search radar).
G.S.	Ground speed.
I.A.S.	Indicated air speed.
I.L.S.	Instrument landing system.

Terms

Instrument Error (in the U.S.A. Calibration Error)	Used in reference to indicated air speed to denote the mechanical error due to incorrect construction of the working parts and the error in scale calibration.
Position Error (in the U.S.A. Installation Error)	Used in reference to indicated air speed to denote the error due to the uneven air flow over the outline of the aircraft in the vicinity of the pressure and/or static orifices.
Track Mesh Point	In a single runway system, the point downwind where the tracks of the individual aircraft come to a focus and merge into a single straight track leading to the touch-down.
Track Mesh Zone	In a system of parallel approaches the area downwind of the runways which contains the track mesh points of all the runways in use.
Single Aircraft Fuel Optimum	The approach procedure which will require minimum consumption of fuel and which could ideally be adopted (under instrument conditions) if there were no other aircraft in the area.

Note: In discussing this subject the term "control" is commonly used but it is capable of a very broad interpretation. In a paper of this type it is essential to distinguish between "control" in the sense of air movement co-ordination, "control" as used in relation to aircraft manipulation and so on. The word has therefore been avoided as far as possible.

2. Principal Assumptions

2.1. Summary

A number of working assumptions are adopted. These are summarised in Table I, with a reference to the sub-section where each is discussed.

2.2. Period under Consideration

To the time that is required for technical development of any new control system must be added the interval necessary for international agreement, for production and for installation of equipment. Hence 1955-6 will

be taken as the start of the period in which any substantially different techniques and equipment could be in operation.

By 1960 new and promising techniques now under study may well be proven; certain military devices now highly classified may be released for civil use. To exploit these advances a further four to six years will be necessary. Rather than delve too far into the realms of conjecture, 1965 will be regarded as the end of the period under consideration.

2.3. Types of Aircraft

Under conditions of war—both hot and cold—civil and military aircraft are often staging through or operating from the same airfields; both types are therefore kept in mind.

2.4. Landing Rate Requirements

It is generally accepted that there is a requirement (civil and military) in North America, Europe and elsewhere for facilities to permit the more rapid acceptance of aircraft at terminals under I.F.R. conditions. It is necessary however to have some quantitative idea as to what this requirement is.

Within military circles requirements have been mentioned for arrival rates of "at least two per minute." These figures would appear to be fully warranted as military targets on two grounds, namely:

(*a*) Landings at this rate (approximately) were required and achieved—although not necessarily sustained for a full hour—under contact conditions during the Second World War.

(*b*) Any attempt to operate an airport at maximum handling rate will lead, with random arrivals, to large individual delays. Bowen and Piercey[1] have made the reasons for this quite clear. If random arrival is a condition it follows that airports and their associated handling facilities should be designed with a large reserve capacity.

Within civil aviation circles similar very high movement rates have been mentioned as future requirements (*see*, for example, Ref. 2). It will be assumed that a peak acceptance capacity of 120 aircraft per hour to 240 per hour is desirable for the more important terminals by 1955, or as soon as possible thereafter. If only the lower figure is accepted, the conclusions of the paper will require little modification.

TABLE I

Summary of Assumptions

No.	*Assumption*	*Discussion Section*
	Period under consideration	
1	About ten years beginning 1955-6.	2.2.
	The traffic	
2	A peak acceptance *rate* of 120 aircraft per hour, and possibly of 240 per hour is required.	2.4.
3	Piston and jet, military and civil aircraft, often mixed, but not rotary wing types are arriving.	2.3.
4	May be coming from many directions.	*None*
5	Arrival times will often tend to show random distribution.	2.5.
6	Radar or other surveillance will be in operation and capable of re-directing errant aircraft—provided that these do not exceed about five to ten per cent. of the total flow.	2.6.
	Aircraft management	
7	Ten per cent.—perhaps more—of the approaches will be manually piloted.	2.7.
8	Aircraft power regulation will not be substantially different from that employed in jet and piston aircraft in 1951.	2.8.
9	In a significant number of cases aircraft speeds may be plus or minus 2½ knots different from that called for, owing to imperfections of instruments and/or aircraft management.	2.9.
10	Aircraft endeavouring to take departure from a well-defined point at a specified time may be plus or minus 30 seconds, early or late (95 per cent. figure), even though they are in the immediate vicinity in good time.	2.10.
	The weather	
11	I.F.R. conditions may extend on vital occasions from 35,000 ft. to a level near the surface (say 100 or 200 ft.).	2.11.

2.5. Distribution of Arrival Times

One flow control system, often discussed, is that in which all waiting is done on the ground at the airport of departure; under this system the signal to depart is given to the aircraft by the controller at the destination airport via the controller at the departure airport. Such a technique will not meet all military requirements and lacks the flexibility to cope with emergency or unpredicted situations. A large diversion programme resulting from weather or from the injection of some "hostile plots" may well upset it.

While some regulation of departure times will undoubtedly alleviate congestion, it will be assumed that aircraft will often arrive in the zone of the destination with something like a random distribution.

2.6. Surveillance

The personnel responsible for monitoring movements in congested areas must have adequate equipment for exercising surveillance. Any such facility, supplemented by communications, provides a means of redirecting or "vectoring" errant aircraft, provided that they are not too numerous. This allows consideration to be given to traffic systems which, initially, will be able to handle only 90 per cent. of the traffic. Any system recommended for adoption, however, should ultimately cater automatically for 95 per cent. of the traffic (at least).

2.7. Automatic Flight Controls

A vital factor in any discussion such as this is the existence in all aircraft or otherwise of precise automatic flying control equipment and the policy governing its use for approach, flare-out and touch-down. In endeavouring to forecast future practice, the following points have been taken into account:

(*a*) Auto-pilots are susceptible to the failures of servo-mechanisms, gyroscopic systems and electronics. While the frequency of these has been reduced to an economic level, the traffic approach system must legislate for a certain number of *approaches* made manually, either because of failure or for purpose of maintaining the manual proficiency of pilots against possible emergencies.

(*b*) Universal acceptance of automatic *landings* would appear to be even less likely than 100 per cent. use of automatic approaches. Not only do the reasons in (*a*) apply but it seems probable that, for several years at least, there will be a reluctance on the part of some pilots to rely on an auto-pilot for the actual touch-down.

(*c*) The possible consequences of a failure at near-stalling speeds and the relatively long "time-constant" for human reaction compared with that of a machine may well preclude authorisation or enforcement of automatic landing for some years.

2.8. Aircraft Power Regulation

Regulation of propulsive power also affects the degree of precision with which the speed can be regulated and on jet aircraft some development is in hand. It will be assumed that a *proportion* of the 1955-65 aircraft will have power control not significantly different from that presently available in such aircraft as the Meteor, Boeing B-47A and the Canberra.

2.9. Aircraft Speed Regulation

A reasonable starting point for deciding assumptions here are perhaps the requirements for award of a pilot's Instrument Rating. The British civil aviation tests for this specify[3] a tolerance of plus or minus 5 knots under most normal conditions with allowances for turbulent conditions. The Royal Air Force in its Flight Test Schedule[4] for award of an instrument rating on jet-propelled aircraft lays down a tolerance of plus or minus 10 knots on precision climbing turns, but does not appear to lay down air speed standards for other conditions.

In a study of aircraft spacing, the important factor is usually the integrated effect of incorrect speeds—rather than momentary maximum deviations. R.A.F. Transport Command has collected a little evidence on this in Dakota (C-47) aircraft. The conclusions[5] suggest that the speed variations have little effect on calculated approach times beyond a few seconds provided that instrument and position errors are allowed for. Without further evidence it would, however, seem premature to accept the thesis that any desired air speed can be maintained with negligible accumulated error.

Further military evidence on this has become available recently. This evidence is based on a very large number of flights with the greater part of the flying done by automatic pilot at constant height. The 95 per cent. error limits were plus or minus $2\frac{1}{2}$ per cent. of distance flown[6].

It might be reasonable to expect some improvement on this performance by 1955-1960 but there are negative factors also, *e.g.* position errors on air speed indicators are

usually negligible at cruising speed but may become significant at the slower approach speeds. Remembering that during descent it is not always particularly easy to allow for instrument error, position error and reading errors, it will be assumed that a steady error (or its equivalent) of plus or minus $2\frac{1}{2}$ knots may be present in a significant number of approaches in I.F.R. conditions. It should be remembered that manual approaches in 10 per cent. of cases or more have already been assumed.

If manual flight is completely excluded, more precise retention of air speed is possible. Experimental work in another connection in U.S.A. in 1950 indicated that control to quite narrow limits is possible in modern aircraft throughout approach procedures. Special equipment, however, was called for and it would be premature to assume general availability before, say, 1957-8. While such equipment may give excellent speed stability, the attainment of a particular speed is far from instantaneous. The ability to *follow* a varying speed reference with a quick dead-beat response is an essential element of many of the proposed terminal approach systems. Present aircraft development programmes do not appear to include much effort in this direction. This consideration gives further backing to the figure of $2\frac{1}{2}$ knots assumed.

2.10. Accuracy of Timing on Setting Course

During some large scale British military exercises, a number of aircraft were briefed to set course over an airfield tower at specified times, averaging about fifteen minutes after take off. An analysis of performance[7] showed that only half of them passed the datum line within thirty seconds of the scheduled time. There was a tendency to be late rather than early.

These aircraft were not using distance-measuring equipment but there were other factors in their favour, *e.g.* visual weather conditions, a recent time synchronisation and a high degree of pilot co-operation. All this suggests the need for improved equipment if aircraft are to adhere to any fine time schedules.

From the evidence it would not be unreasonable to assume that the accuracy of timing when setting course has a 95 per cent. scatter of plus or minus 60 seconds. However, it will be assumed, somewhat optimistically, that with improved devices the 95 per cent. scatter is reduced to plus or minus 30 seconds for aircraft departing from "the track mesh point." Any scepticism as to the practicability of this will only support the author's conclusions.

2.11. Weather Conditions

It is difficult to decide exactly what thickness of cloud should be assumed in planning a high density approach system. If the weather is such that aircraft can rendezvous above the clouds in good local visibility at, say, 15,000 ft., and take departure in turn, there are a number of possibilities. These conditions are not infrequent in the British Isles. Nevertheless more rigorous conditions are assumed for two reasons:

(*a*) A universal solution is preferable to a regional one. Remembering the extensive cloud layers that are met in Equatorial regions and such places as the Indo-Burma frontier, it does not seem wise to assume that a clear stable layer suitable for aircraft rendezvous will invariably be available below 30,000 to 35,000 ft.

(*b*) Any system which assumes only a limited cloud thickness may, in exceptional weather conditions, break down with catastrophic results.

3. Some Preliminary Concepts

3.1. Introduction

In this section are discussed:—

(*a*) the essential elements that must be present in any traffic control system.

(*b*) the normal modes of regulating final approach times.

(*c*) the different phases of an individual approach.

(*d*) the length of the common straight approach track.

(*e*) recovery of schedule during approach from a distance.

(*f*) the usual flight management techniques.

3.2. Elements of the System

The principal elements of a terminal traffic control system are shown in Fig. 1. The functioning of each element is discussed in relation to specific types of spacing in later sections.

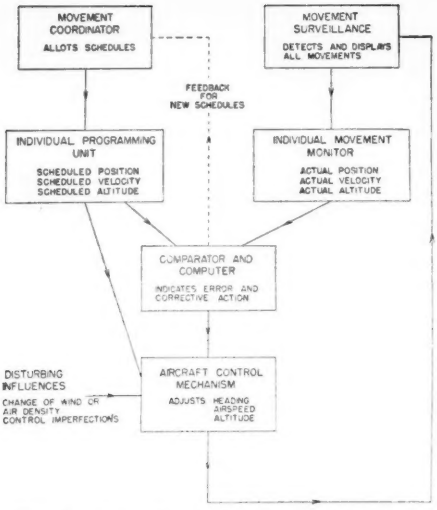


Fig. 1. Generalised air traffic control system.

The function of the movement co-ordinator is to allot each aircraft a unique moving block of air space—a dynamic niche in the atmosphere. The motion of these blocks must be defined in terms of time and position (actual or relative) but the paths traced out by them need not be linear. The precise boundaries of each block must be known and a safety gap or space is required between adjacent ones. Lateral, longitudinal or vertical spacing of the blocks may be adopted.

Once an aircraft has been assigned to a particular block, the requirement is to get the aircraft to the centre of the block and keep it there. This implies manoeuvring the aircraft to ensure arrival at the right position at the right moment; it also postulates acquisition by it, simultaneously and asymptotically, of the correct velocity (*i.e.* heading and speed). This is generally accepted to involve a knowledge not only of position of the aircraft, but of velocity and rate of change of velocity. Provision of all this information is the function of the individual movement monitor or navigation system (Fig. 1).

This position and movement information may be derived in the aircraft or on the ground. Normally it is required on the ground for surveillance purposes and in the air to provide essential data for the guidance system. In some systems such as G.C.A. and A.G.C.A., information derived on the ground is passed to the aircraft. Sometimes the aircraft transmits the information to the ground control. Often both systems are used.

Assuming that the aircraft is provided with continuous and exact navigational information, the performance of the overall system may still depend on a further element, namely the efficiency of aircraft management. The flying controls and power controls in the aircraft must be such that the aircraft can comply with the schedule and guidance given to it.

The generalised block diagram in Fig. 1 obscures two vital elements of the system, communication and aircraft identification equipment. Some improvements in both these systems seem probable and they will not be discussed in any detail.

3.3. Modes of Regulating Approach Times

It is generally considered that there are three methods of regulating approach or entry times:—

(*a*) by provision of a holding procedure or pattern after arrival in the vicinity of the terminal, *i.e.* by "stacking" in some way.

(*b*) by varying the approach routes in the later stages of the approach so as to adjust time of entry at a "gate." This is a form of "holding" but makes the queue less obvious and less concentrated.

(*c*) by "scheduling" or adjusting speeds of approach from a considerable distance (and, if necessary, adjusting take-off times).

Reliance on a holding pattern (*a*) is unsatisfactory for obvious reasons. Apart from the inherent inefficiency, it is not easy to achieve, precisely, a specific delay and at the end of it ensure that the aircraft appears at the right place, at the right height and with the desired speed and heading. Apart from this difficulty delay can usually be effected only by finite steps of definite duration. Bowen and Piercey[1] have already shown that the holding procedure must be capable of fine control, *i.e.* of very small steps, and this is somewhat difficult to arrange. Furthermore, with many new types of aircraft it will be desirable to arrange for holding to take place at a substantial height. This will normally be followed by a fairly considerable descent during which any fine steps of separation, achieved before departure from

the stack, may well be impaired due to variations in descent paths, in descent rates and the vagaries of the atmosphere.

The second method (*b*) is particularly useful in effecting small delays. Assuming however that the mass of aircraft normally use the most direct or the most economical route, it is inefficient to vary this route by any *large* amount. Electronic engineers have proposed from time to time neat systems using this principle but have sometimes overlooked the fact that the aircraft, after its diversion, must arrive back on schedule with its heading and speed stabilised at the correct figures.

On most aircraft *some* adjustment is possible to *en-route* speed (*c*) without very detrimental effect on miles per lb. of fuel. This will often allow the time of arrival to be *advanced* (within limits) as well as retarded, without any significant expenditure of fuel. It seems logical that this be exploited.

This paper is concerned only with (*b*) and (*c*), *i.e.* methods which will minimise the necessity for holding patterns and stacks at destination. Some holding procedure will probably be essential if only to handle "overshoot" aircraft and to cater for emergencies, but this should be regarded as an accessory. The system to be sought in the first instance is the system which will eliminate stacking as the routine mode of operation.

3.4. Phases of the Approach

Figure 2 shows the different phases that constitute an approach and landing. The ultimate ideal system would presumably eliminate the "common straight track" and thus reduce the overall distance flown.

3.5. The Stabilised Final Approach

During the last portion of the approach, the flare-out and the touch-down the pilot will wish to concentrate on stabilising his air speed and his alignment so that both are corrrectly set when he passes over the fence. It is undesirable during this time to ask him to make any further adjustments for spacing purposes, and so correct spacing must be achieved before the aircraft passes point *B*. This phase (*BA*) will be referred to as the stabilised final approach, with *B* as the "inner gate."

The Royal Air Force Transport Command, in one of their papers[8] mention 3 to 4 miles

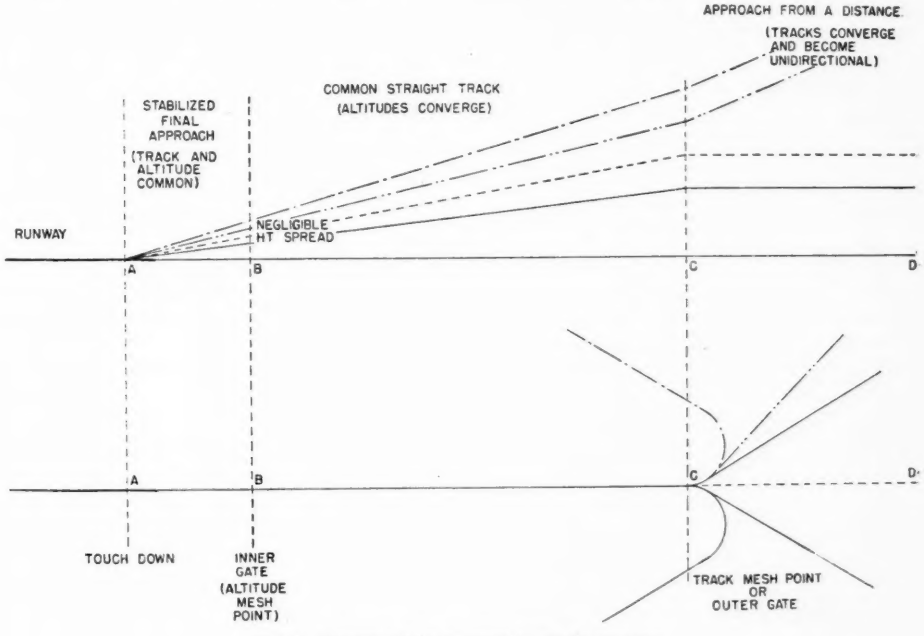


Fig. 2. Phases of the approach—single runway.

as a reasonable figure for the distance from touch-down after which attention can no longer be given to fast/slow indications. Estimates, however, vary widely.

For the purpose of this study the distance *AB* will be taken as about 3 miles, but a couple of miles either way will not greatly affect the conclusions.

3.6. Extent of the Common Straight Track

It is now necessary to determine the length of the common straight track, *BC*. Assume that, at the track mesh point *C*, there is some mal-spacing—in particular that one aircraft is half a minute behind its allotted schedule.

Suppose that the pilot has an instantaneous indication of his error at the track mesh point so that he immediately takes action to increase his speed by $\frac{1}{5}$, that is he accelerates from V knots to $V(1+\frac{1}{5})$. The closing distance for different speeds is shown in Fig. 3 by the heavy line. (The closing speed is then $V/5$ knots and the distance to be closed is $V/(2\times 60)$ miles. The closing time is therefore $5/2$ minutes.)

Assuming a total time allowance of one minute for acceleration and later, deceleration back to the correct speed after the schedule has been recovered, the distance covered in the overall recovery operation is as shown by the broken line. At 150 knots, this is 10 miles, at 240 knots it becomes some 16 miles. These distances compare not too unreasonably with the straight runs used now for alignment on G.C.A. and I.L.S. with somewhat slower aircraft which have better braking qualities. If this straight run is to be used not only for alignment (as at present) but to rectify these small spacing errors, some such extension of its length seems necessary.

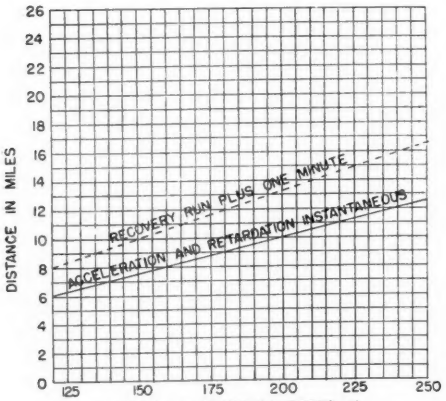


Fig. 3. Distance traversed in recovery of schedule if half a minute late.

Speed increase V/5
Time to recover 5/120
Distance during recovery (5/120)(V+V/5)=V/20

All Weather Flying Division, United States Air Force, have also been studying[9] the length of this common straight track from a different point of view. It is desirable to be able to accept aircraft approaching with different speeds and the implications of alternate fast and slow aircraft were examined under single glide slope conditions. Fig. 4 is extracted from their study[9] and assumes that the fast aircraft approach with a constant ground speed of 160 knots, and the slow aircraft approach with a constant ground speed of 105 knots. This is possibly an extreme case but brings out certain useful points. If a one-minute space separation rule is applied and an eight mile (only) straight common track is assumed, it is found that the fast aircraft may not enter the final approach gate until 2.6 minutes have elapsed from the time of entry of the preceding slow aircraft. This means an acceptance rate at the outer gate of 1.8 minutes per aircraft compared with the one per minute possible with a homogeneous flow.

By studying the same problem with common straight tracks of a different length, the All Weather Flying Division demonstrated that for a given spread of approach speeds, "the decrease in acceptance rate (below that possible with homogeneous aircraft) is proportional to the length of the common straight track." In other words the longer the common straight track the slower the acceptance rate with mixed aircraft.

There is thus a conflict of requirements due to:—

(*a*) the advantage of a short distance in facilitating acceptance of aircraft approaching at different speeds.

(*b*) desirability of a long straight track to permit some schedule recovery as already outlined. The overall practical rate of acceptance is increased if aircraft which are off-schedule by 30 seconds can be accepted at the track meshing point.

The solution appears to lie in:—

(*a*) reduction in the spread of approach speeds, that is, by grouping similar

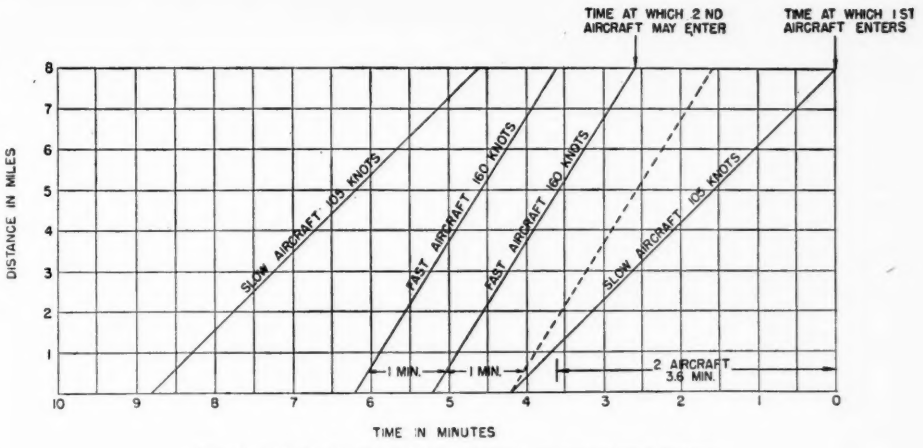

TIME AT WHICH 2 ND AIRCRAFT MAY ENTER
TIME AT WHICH 1 ST AIRCRAFT ENTERS
DISTANCE IN MILES
SLOW AIRCRAFT 105 KNOTS
FAST AIRCRAFT 150 KNOTS
FAST AIRCRAFT 150 KNOTS
SLOW AIRCRAFT 105 KNOTS
1 MIN.
1 MIN.
2 AIRCRAFT 3.6 MIN.
TIME IN MINUTES

Fig. 4. Effect of fast and slow aircraft on one-minute system.

aircraft. Multiple runways, if adopted, should permit something in this direction; or

(*b*) reduction in arrival time tolerance at the outer gate, that is, to something much better than 30 seconds; or

(*c*) adoption of some altitude spacing at the outer gate. This implies variable glide paths; or

(*d*) a combination of these.

Of these solutions the most difficult of accomplishment in the immediate future appears to be (*b*).

It will be assumed that for some years this will make it desirable to adopt, normally, a common straight track of 12 to 15 miles, *i.e.* of sufficient length to permit some schedule or spacing refinement. This does not preclude feeding an aircraft into the straight track at a shorter distance where the aircraft can be relied upon to achieve the higher punctuality that is thereby postulated—or where gaps in the traffic flow permit.

Downes[10] in Australia found that turning in from an eight mile orbit allowed insufficient time on the final straight approach to align the aircraft on the proper bearing even with a C-47 Dakota, and there was a predominant tendency to overshoot when turning on to the straight common track. With faster aircraft both the amplitude of the overshoot and the distance covered during corrective "track-setting" might well be greater. Improved guidance and instrumentation should partly counterbalance this but it seems safest to plan on, say, 12-15 miles.

Assuming the ground speed on this phase of the approach is from 120 to 150 knots, the time involved on a 15-mile straight run is from $7\frac{1}{2}$ to 6 minutes. During this time the descent rate may be something under 1,000 ft. per minute. It follows that the altitude at *C* should normally not be more than 8,000, except perhaps with certain military aircraft using higher descent rates, when 12,000 ft. might be assumed as a normal upper limit for the track mesh point.

3.7. Recovery of Schedule during Approach from a Distance

So far it has been assumed that aircraft will be accepted at the track mesh point only if they arrive within half a minute of the schedule; it is now necessary to study what is involved in meeting this condition. Consider an aircraft which is ninety seconds late and is endeavouring to regain one minute of schedule before it arrives at the track mesh point *D*.

The principal differences between this recovery problem and the preceding one will be:—

(*a*) The aircraft will probably be moving faster and at more diverse ground speeds.

(*b*) The altitudes will be diverse and rather higher. One implication of this is that speed stabilisation and acceleration will both be slower.

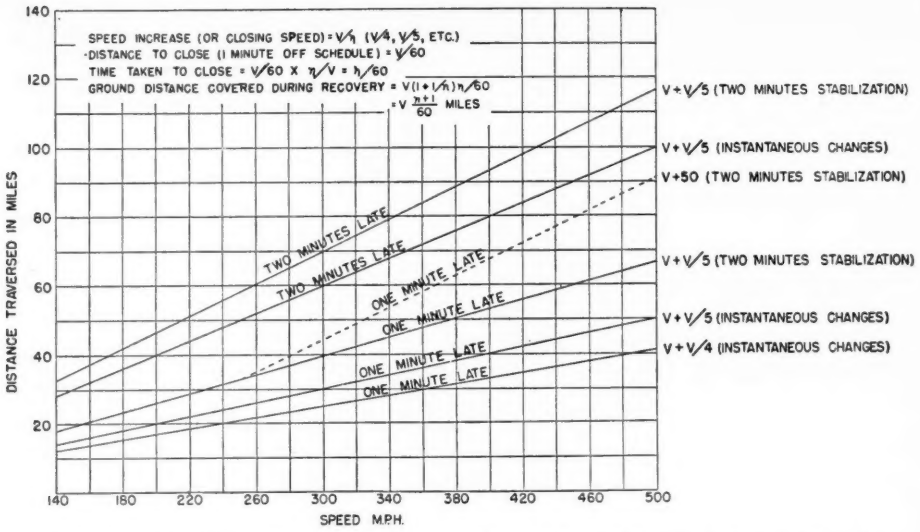


Fig. 5. Distance traversed while recovering schedule at high speed (approach from a distance).

Assuming that aircraft speed is increased by $V/5$, the corresponding distances to effect recovery are shown in Fig. 5. Distances are shown also for an aircraft which is two and a half minutes behind its intended schedule and seeks to recover two minutes. For the "Instaneous Change" line, the assumption is that speed is increased instantaneously and that, when required, the speed returns to normal again without any delay.

In practice the speed is not increased instantaneously on receipt of the "behind-schedule" information. There will be a delay which depends on:—

(*a*) The human reaction time.
(*b*) The extra thrust available.
(*c*) Altitude.
(*d*) Aerodynamic characteristics.

Lush's remarks[11] "on relaxation time" seem to be in accord with answers provided by test pilots at Wright-Patterson Air Force Base on multi-jet aircraft. Assuming that the change in speed will often be made at heights of about 25,000 ft., it seems reasonable to assume that two minutes may be spent either in accelerating, or in subsequent speed stabilisation. This increases the distance traversed during schedule recovery to that shown by the "Two minute stabilisation" lines of Fig. 5.

The assumption of a speed increase of one-fifth may be questioned particularly in relation to high-altitude flight. If instead of this, an increase of 50 knots is assumed the broken line of Fig. 5 is derived.

Looking at all these results and assuming that the system must cater for aircraft with a *ground* speed of up to 420 knots, the distance traversed in the recovery of two minutes is as much as 100 nautical miles. It follows that it must be possible to detect how late the aircraft is, and pass it to the aircraft for action at a distance of 100 nautical miles from the outer gate. The distance from touch-down is then the sum of:—

(*a*) The stabilised final approach distance (no spacing adjustments)—3 miles.
(*b*) the straight common track (small spacing adjustments)—say 12 miles.
(*c*) the distant approach (two minute schedule recovery)—say 100 miles.

This gives a total precise navigation zone of about 115 nautical miles.

If three minutes *en route* delay is to be corrected before reaching the outer gate, the distance involved (based on acceleration to $6V/5$ and a ground speed of 420 knots) becomes 140 nautical miles from the outer gate, or about 155 miles overall. It may be argued that the adoption of such a high speed

in this phase is not warranted, but the aircraft may be descending from 35,000 ft. to 10,000 ft. and it may be downwind as far as the turn at the outer gate. For four minutes' recovery the corresponding distance (on the same assumption) is about 200 miles.

It may well be argued that the system should cater for aircraft up to three minutes late (and perhaps more), in the 1955-1960 period at least. Any such condition, coupled with a demand for an undelayed approach under dense traffic conditions, postulates a very considerable range for the terminal approach navigation and guidance system. The range performance (90 per cent. or 95 per cent. zone) of electronic ground-based systems operating at frequencies higher than 100 mc/sec. would seem to be marginal and perhaps inadequate in this connection, unless supplemented by other accurate fixing systems. This is particularly so when considered in relation to approaches from the ocean such as occur at New York, Colombo, Honolulu, Sydney, and current standards of punctuality at the end of long sea crossings.

3.8. Aircraft Management and Programming Techniques

The movement programme for any individual aircraft must be devised on the basis of some practicable flight technique. The flight techniques usually considered for the purpose of regulating forward progress are:—

(*a*) Flight at specified or constant "rectified air speed" (R.A.F.) or "calibrated air speed" (U.S.A.).

(*b*) Flight at specified or constant Mach number.

(*c*) Flight at specified or constant ground speed (constant E.T.A.).

(*d*) Flight at specified or constant linear distance or linear flight time from an aircraft ahead.

(*e*) As for (*d*) but on non-linear tracks.

The necessary equipment for (*a*) and (*b*) already exists and, with certain limitations as to accuracy, could probably be provided in all large aircraft by 1955.

Flight at constant ground speed (*c*) postulates either:—

(*i*) constant knowledge of the wind (as well as true air speed) plus a computer; or

(*ii*) direct measurement of ground speed.

A computer to allow for wind is not very practicable during the approach as the wind is constantly changing during the descent. A device to measure ground speed directly on linear tracks could be developed fairly readily from D.M.E. as explained later.

The equipment required for maintaining constant linear distance from an aircraft ahead (*d*) would be similar to military "A.I.," that is to airborne search equipment with a lock follow antenna and range measuring facility.

With this background on systems generally and the possible modes of operating them, an attempt is now made to study longitudinal, and lateral spacing.

4. Longitudinal Spacing on the Common Straight Track

4.1. Introduction

Under good visual conditions aircraft are able to land in succession on a single runway at better than one a minute, but under I.F.R. conditions this deteriorates to one every two to three minutes, or worse, and usually involves an elaborate ground control organisation. The majority of currently practiced schemes demand detailed human surveillance of aircraft spacing and a steady, or considerable, flow of correcting instructions, which seldom contain any longitudinal *rate* information and are usually prompted by incipient mal-spacing. Thus correction tends to be a trial and error process. Its success depends very much on the experience of the ground controller and the skill shown in the management of the aircraft. A sustained landing rate of two per minute is indeed an achievement under these conditions. Without radical changes any large increase beyond this figure appears unlikely.

It would be logical to approach the problem of longitudinal spacing where it begins, *i.e.* on the distant approach, but it is convenient to start from the other end, *i.e.* from the touch-down point, and work backwards. In this section will be discussed the spacing of aircraft proceeding in a single stream along the common straight track which leads from the track mesh point to the touch-down end of the runway in use. A one-per-minute landing system will be assumed as the immediate objective.

In connection with this common track, three points must be kept in mind. First it has been inferred already that its length, including the final stabilised element, is about 15 to 18 miles. Secondly, it is assumed that

95 per cent. of the aircraft are able to take their departure from the track mesh point within ± 30 seconds of a stipulated time. (The problems involved in achieving the latter condition are considered later.) Thirdly, it is advantageous if this longitudinal spacing can be associated, at the track mesh point, with some vertical separation.

In certain instances graphs are used to show, against a time base, the plan distances covered by aircraft after departure from the track mesh point. To add a touch of realism the wind and temperatures will be taken as those observed at Selfridge Air Force Base, near Detroit, U.S.A., at 1,500 hr. Z on 29th April 1951 (*See* Appendix). On this occasion the lapse rate did not vary unduly from the I.C.A.N. standard atmosphere and there were no inversions; but the wind at 5,000 ft. did veer somewhat from the surface direction. The surface wind was 180 degrees and, to bring out certain points, it will be assumed that the runway used was 150 degrees. Since working out the examples the author has discovered that there is no such runway at Selfridge but this is not material.

4.2. Possible Flight Techniques

If one per minute is to be achieved on a single runway without both elaborate surveillance and large ground staffs, it seems essential to do one of two things:—

(*a*) provide in each aircraft a complete pictorial situation display so that each pilot, from the cockpit, can co-ordinate his movement with those of other aircraft. Under visual conditions pilots do show great skill and judgment in attaining and maintaining spacing so that if they can be given the vital elements of the picture, under I.F.R. conditions, the problem may be solved. The author believes the Civil Aeronautics Administration has a project at Indianapolis of this type—using modified Teleran equipment—and the results will be of interest. Universal fitment of any such complex devices (when fully developed) appears to be too much to expect within the period under consideration and they will not be further discussed; or

(*b*) establish in advance a movement programme (either absolute or relative) for each aircraft and provide means for the aircraft to comply closely with it. The facilities provided for the pilot should be such that the majority of aircraft *automatically* stay in their allotted dynamic niche. Only the *occasional* aircraft should err from the space that is intended for it. Corrective instructions should be the exceptional — not the normal — occurrence. The requirement for human surveillance should be reduced to that of a monitor.

Attention will be restricted to the second of these approaches.

The problem is therefore to establish for each aircraft leaving the track mesh point a programme of movement which is simultaneously:—

(*a*) amenable to co-ordination with the programmes of other aircraft.

(*b*) acceptable from the point of view of aircraft management.

(*c*) amenable to simple and rapid communication between those concerned on the air and the ground. For this reason the movement timetable should be brief and simple.

The accepted techniques of aircraft management are examined from these points of view in the following sequence:—

(*a*) Specified indicated air speed(s) on the common straight track.

(*b*) Specified Mach number on the common straight track.

(*c*) Specified true air speed(s) on the common straight track.

(*d*) Specified ground speed(s) on the common straight track.

(*e*) Specified linear distance or flight time from the aircraft ahead using airborne search equipment.

(*f*) Constant linear distance or flight time from the aircraft ahead using ground surveillance or precision approach radar.

4.3. Specified Indicated Air Speed Techniques on the Common Straight Track

From the point of view of aircraft management the simplest flight programme is probably one that calls for constant I.A.S. The average pilot has been trained to perfect this on his various instrument courses, and certain semi-experimental automatic systems in U.S.A. are able to keep closely to a pre-set figure.

Communication of the assigned programme places little demand on communications. Co-ordinating the movements of several aircraft using this technique is simple so long as all aircraft are subject to the same wind effect—that is, so long as they operate at each height for the same period.

The practical questions that arise are:—

(*a*) what tolerances are permissible in air speed without significant effect on spacing?

(*b*) what difference is permissible in the initial altitude of two consecutive aircraft at the track mesh point? As was indicated earlier, altitude separation would be useful here, not only as a palliative to small degrees of mal-timing, but to help to accommodate aircraft with different approach speed or descent characteristics.

Considering (*b*) first, let us examine the effect of different descent rates on the plan spacing of two aircraft carrying out their final straight approach at a standard specified air speed. Two similar aircraft will be assumed to depart from the track mesh point at Selfridge Field at an interval of one minute. Both are flown at exactly 150 kts. rectified air speed. Their initial heights and descent patterns are as follows:—

	At track mesh point		*Rate*	*Level*
	Time	*Height*	*of descent*	*out*
A/c. A	10.00	10,000 ft.	1,000 ft./min.	1,000 ft.
A/c. B	10.01	5,000 ft.	500 ft./min.	1,000 ft.

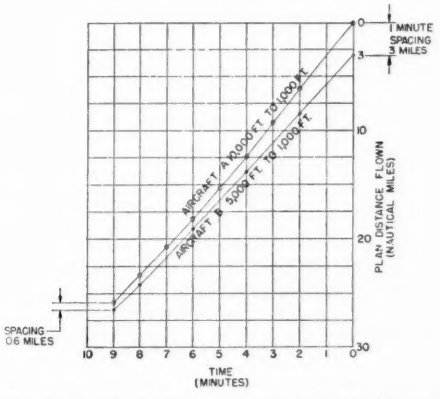


Fig. 6. Standard air speed approach with different glide paths at Selfridge Field, 29th April 1951, 15.00 hr. Z, track 150° true, both aircraft 150 knots I.A.S.

The ground speed of each, allowing for actual winds and air density, was computed at small intervals and the plan distance covered entered on Fig. 6. It will be seen that the original safety spacing of one minute (3 miles) at the track mesh point has been reduced, *without any allowance for imperfections in aircraft management*, to about 0.6 miles or 15 seconds by the time both reach 1,000 ft. Small errors in taking departure and in regulating air speed could reduce this margin even further.

Although this example is not typical of every case where there is an initial altitude difference of 5,000 ft., it does indicate that such a spread can result in a significant loss of spacing accuracy under certain conditions. The precise altitude spread permissible at the track mesh point would depend on the temperature lapse rate and the wind veer. Under more normal conditions it seems reasonable to surmise that, in a one minute spacing system, it would be reasonably safe to employ the "specified constant air speed" technique with an initial altitude separation at *C* of perhaps one or two thousand feet provided that:—

(*a*) the common straight track is not longer than about 18 miles; and

(*b*) the same effective air speed is maintained in both instances within about ± 3 knots (This is discussed later); and

(*c*) spacing is monitored to detect any convergence due to coincidence of unfavourable factors.

In a half a minute separation system much more rigorous conditions would be postulated.

Regarding air speed tolerances, if the differences are small (less than 15 knots) and the altitude paths similar, differences in wind effect should not be significant over the small time that elapses between the track mesh point and the touch-down. It has already been assumed that this may be a run of about 18 miles. The change in spacing or convergence over this distance when a fast aircraft follows a slow aircraft from the track mesh point is then as shown in Table II (ignoring wind).

Table II shows that adjacent aircraft, initially spaced one minute apart, must adhere fairly closely to a standard air speed. If the standard air speed is high, the tolerance can be increased.

Where adjacent aircraft, owing to differences in their flying qualities must operate

TABLE II

Air speeds: knots			Time to fly 18 miles:	Spacing loss:	Separation distances: miles	
Slow A/c.	Fast A/c.	Closing	min.	miles	Desired*	Actual
120	+10(130)	10	9.0	1.50	2.00	0.50
150	+10(160)		7.5	1.25	2.50	1.25
180	+10(190)		6.0	1.00	3.00	2.00
120	+15(135)	15	9.0	2.25	2.00	−0.25
150	+15(175)		7.5	1.87	2.50	0.63
180	+15(195)		6.0	1.50	3.00	1.50

*For one minute separation.

at widely different air speeds, a suitable adjustment must be arranged in the initial acceptance spacing at the track mesh point. In these circumstances the differential effects of wind should be allowed for and programme co-ordination becomes complicated. This is because it is difficult to compute the relative positions of different aircraft at any future moment without feeding into the computer a large number of air mass conditions for different altitudes. The figures for these may change from hour to hour.

To sum up the use of constant air speed technique in a one minute system:—

(*a*) it appears to be practicable on this leg with a group of homogeneous aircraft. The spread of height permissible at the track mesh point should not generally be more than 2,000 ft. Constant surveillance would be necessary if this height separation were exploited to avoid any complications which might arise due to coincidence of unfavourable factors.

(*b*) if different types of aircraft make it necessary to vary the air speed in successive approaches by 10-15 knots, a suitable adjustment to initial spacing is necessary. For this a simple table might perhaps be adopted but there would be some reduction in overall acceptance rate.

(*c*) if the spread of air speed must necessarily exceed this, movement co-ordination becomes exceedingly complex.

(*d*) apart from ground surveillance, there is no device to perform the comparator function (Fig. 1) or to show possible cumulative errors.

While having interim application under specialised conditions, this system has these inherent limitations which make it less flexible than a constant ground speed system (discussed later). Development to "better-than-a-minute" standard would demand exacting flight management with respect to rate of descent, as well as air speed; and it would postulate tight acceptance tolerances at the track mesh point. Except as an interim method of handling homogeneous groups, the technique is not particularly promising nor does it inspire confidence in very turbulent conditions.

4.4. Constant Mach Number Technique on the Common Straight Track

Constant Mach number technique has been suggested by some writers for the main part of the descent. It is discussed in this section mainly to show that it does not fit in very well with the final phase of the approach.

It has already been noted that the common straight track is not likely to extend above 8,000-12,000 ft. Between this level and the surface, the speed of sound will normally vary over something less than 30 knots[23]. The Mach number used for this phase is likely to be rather less than 0.40, and therefore flight at constant Mach number is unlikely to involve changes of true air speed greater than $30 \times 0.40 = 12$ knots. In other words the descent would take place with the *true* air speed closely controlled but increasing gradually at roughly one knot per thousand feet. For the pilot, this would involve some power adjustments but probably not as much as required for a constant ground speed approach.

Against the adoption of such a technique:

(*a*) Machmeters are usually graduated rather coarsely in the low speed range and some design improvement would be necessary.

(*b*) there is no readily available device to show the effect of cumulative errors, *i.e.* to perform the comparator function continuously (Fig. 1).

(*c*) indicated air speed must usually be monitored during this phase for safety reasons. Reference to a second instrument would not be desirable unless there were some very considerable advantage over the constant indicated air speed technique.

(*d*) adoption of altitude spacing at the track mesh point is limited owing to the effects of differential winds.

(*e*) there is difficulty co-ordinating the movements of aircraft which approach at different speeds.

4.5. Specified true air speed on the common straight track

The remarks concerning constant Mach number technique and constant indicated air speed technique are largely applicable to flight at constant true air speed. Communication of the flight programme is again simple. The amount of power adjustment required will be slightly less than that implied for constant Mach number for, as the inner gate is reached, the indicated air speed will not have to be increased to the same extent. Changes in air density do not have to be considered but it is still necessary to ensure that consecutive aircraft are subject, closely, to the same winds, or to adjust initial acceptance spacings accordingly. If a height spread is desired at the track mesh point, this difficulty arises immediately.

While provision of true air speed indication would not be a serious problem it is not at present generally available in aircraft. While it might perhaps be of some use on this phase, it does not make any real contribution in other phases or to the solution of the problem of mixing fast and slow aircraft; in view of this, provision of true air speed indicators for this particular purpose *only* would scarcely be warranted.

4.6. Constant linear spacing technique using airborne search equipment

As the principal object is to maintain aircraft at specified minimum spacings, direct measurement of the linear distance between consecutive aircraft would seem to be a logical approach to the problem. It is well known that during the Second World War military aircraft used A.I. sometimes with a " lock - follow " antenna and a range measuring facility. Some adaptation of these techniques could certainly provide a continuous indication of the distance to the aircraft ahead.

In using such a device on the approach there are certain problems:—

(*a*) it would be most necessary to ensure that the search radar was locked on to the correct aircraft. Some form of air-to-air identification seems therefore to be a pre-requisite.

(*b*) in so far as details of A.I equipment have been released, it seems that existing equipment gives information on air-to-air ranges but not as to the rate of change. The addition of rate information would be desirable, perhaps essential, to avoid undue oscillations and/or pilot fatigue. This is equivalent to asking for " blind station keeping equipment " rather than A.I.

(*c*) while any such system would provide immediate indication of convergence (and this information would be of value) it is not clear how it would provide the necessary flight instructions for a fast aircraft following a slow one—or *vice versa*. An aircraft overshooting might also present a complication.

(*d*) Another problem arises if an aircraft arrives at the track meshing point, say 30 seconds late, in a one minute system. If only air-to-air distance measuring equipment is used, there will be a tendency for the late aircraft to retard the group of following aircraft. If a steady flow of aircraft at one minute intervals has been programmed at the track meshing point, it is most desirable that the system adopted should not tend to perpetuate the lateness of any one aircraft. It may well be argued that the best way of doing this is for all to use a fixed reference position, that is a beacon on the ground instead of one on the preceding aircraft. This is equivalent to the use of constant ground speed technique.

(*e*) performance of conventional A.I. equipment at low altitudes presents technical problems, the solution of which may involve added complexity of equipment.

It seems reasonable to infer that the use of airborne spacing equipment may well have useful application to a group of homogeneous aircraft, particularly if they are carrying such equipment for other purposes. A delay in the arrival of one aircraft will tend to be perpetuated in the succeeding aircraft but this may be acceptable if these delays can be taken up in periodic gaps between the arrival of different waves.

From the civil viewpoint it seems *im*probable that the necessary equipment, suitably simplified, will be available with rate information, air-to-air indentification, lock-follow antenna, etc., in all or in sufficient aircraft before 1960—if by then. Much remains to be done in the way of experiment and trial; if these are successful the immediate application is to the military who may well monopolise the system for some time.

4.7. Constant Linear Spacing using Ground Surveillance or Precision Approach Radar

Development work with G.C.A. in the U.S.A. includes provision of an automatic overtaking alarm signal derived presumably from range gating signals. The author has not seen details of this interesting project and is reluctant to comment. Flight management requirements however suggest that such a signal, although useful, is only a partial answer to the spacing problem. Unless the pilot's directions take cognisance of his speed as well as his position, aircraft manipulation difficulties may well arise. If the system depends on inter-aircraft separation only, there are also the problems associated with a moving reference which have been mentioned already, namely, perpetuation of delays and the possibility of increasing oscillation about the correct position. Trials will indicate whether these difficulties are theoretical only. In so far as the system provides continuous up-to-date information, with no accumulated errors, it certainly has considerable merit. Of the systems discussed so far this is the first which has an automatic "comparator unit" (Fig. 1) to check actual separation against intended spacing.

4.8. Flight at Specified Ground Speed (Constant E.T.A.)

A principal aim is to have the aircraft arrive at the runway at the scheduled time. Actual E.T.A.s are normally forecast on the basis of constant ground speed. If this ground speed can be adhered to exactly, aircraft will arrive at the planned acceptance moment. If there are small divergences from it, the cumulative effect of these may result in the aircraft being appreciably late or early.

By means of D.M.E. it is possible to measure continuously the linear distance to touch-down. If the actual ground speed is also known, time-to-go can be derived and hence the E.T.A. based on the current rate of progress. If this is used in conjunction with the scheduled arrival time as a Go Fast/Go Slow indicator, the problem of cumulative error referred to above is eliminated. To keep an aircraft in its correct dynamic niche it is necessary for both E.T.A. and ground speed to conform to those planned. This sub-section is concerned with approaches programmed on a basis of constant ground speed and it will be assumed that the pilot has constant up-to-date indication of:—

(*a*) his actual ground speed and the E.T.A. derived from this; or

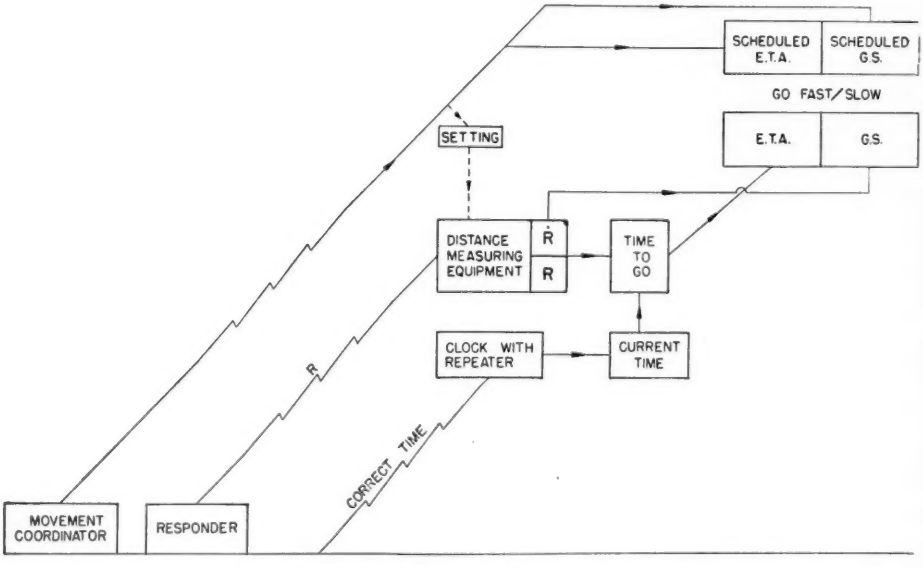


Fig. 7. Suggested off-schedule indicator for linear tracks.

(*b*) an equivalent off-schedule indicator combining in effect both these pieces of information.

Equipment to permit flying at constant ground speed (constant E.T.A.) could be developed fairly readily from D.M.E. One D.M.E. produced in the U.S.A. in 1949 (in service trial quantities) did in fact indicate ground speed continuously, but with only limited accuracy. Combining this indication (suitably smoothed and refined) with a clock, it is possible to show E.T.A. based on current ground speed, as shown in Fig. 7. There are other ways of achieving similar results, *e.g.* Minneapolis Honeywell is developing an "Automatic Flight Schedule Controller" which endeavours to perform the same function[12]. It seems clear that the necessary equipment for constant ground speed approach on this short common track approach could be produced and brought into use in large quantities within the next five to seven years—perhaps sooner.

For movement planning and co-ordination, flight at a constant ground speed is a great simplification. As distance traversed is proportional to elapsed time, the plan position of any aircraft at any moment is readily available; it can be shown on a linear time-distance graph, as in Fig. 4, or displayed by an index moving at a steady rate. Design of a computer to allot unique schedules is greatly simplified. Co-ordination of fast and slow aircraft is not too difficult as relative positions at any future moment can be calculated easily.

For aircraft management the situation is not quite so favourable. Unless both altitude and weather are kept constant, the indicated air speed must be varied to compensate for the effect of changing atmospheric density and changing wind. This involves some throttle jockeying, apart from any that may arise for purposes of schedule recovery. However this phase of the approach will extend only from about 8,000-12,000 ft. down to about 1,000 ft., or perhaps lower.

To study what is involved in the way of air speed adjustment, Fig. 8 has been prepared to show the rectified air speed which, at Selfridge Air Force Base on the day selected, would correspond to a constant ground speed of 160 knots. It will be noted that a variation of air speed from 119 knots to 163 knots is postulated between 10,000 ft. and 1,000 ft.

This rather large variation is due partly to the fact that, on the day in question, the wind at 6,000 ft. to 8,000 ft. was almost down the runway in use, that is, opposite to the landing direction (*see* Appendix). This condition does not occur every day but a variation of that magnitude is not infrequent when the aircraft traverses a front, or when it is flying in the vicinity of tropical thunderstorms. Its possibility cannot be ignored. It should be remembered also, that no allowance was made in this actual example for change of wind or temperature due to the change in location of the aircraft, other than in the vertical plane.

While the range of air speed called for is 44 knots, it is not necessarily beyond the limits available to the pilot. Perhaps if the aircraft were of a type with a high wing loading the pilot might be unwilling to comply with the requirement for 119 knots. In these circumstances the aircraft could be regulated to a ground speed of, say, 170 knots in lieu of 160 knots used in the graph. This would raise the lowest air speed called for to 129 knots approximately but, on the other hand, it involves flying at an air speed of about 173 knots at the inner gate. This might be regarded as a little high at this point—the start of the stabilised final approach. In fact, a constant ground speed approach accompanied by a descent will often involve arrival at the inner gate with an indicated air speed rather on the high side.

If the change of altitude during this straight run-in is reduced, the range of air speed adjustment required is reduced accordingly. In the foregoing example the change of air speed corresponding to 4,000 ft. descent is never more than 29 knots. With other conditions this might perhaps be as much as 40 knots (and exceptionally, more); this should be within the range of speed variation possible—and often leave some margin for those aircraft who are trying to overtake their schedule. As the change of height is a principal determining factor on the degree of adjustment that may be called for, it is useful to examine at this stage the altitude spread that, if possible, should be catered for in the scheme.

The change in altitude during this phase must be such as to meet two requirements:—

(*a*) it must permit a practicable glide path or paths. Over a 15 mile straight approach, the change of altitude is about 1,300 ft. per degree of angle of glide. It follows

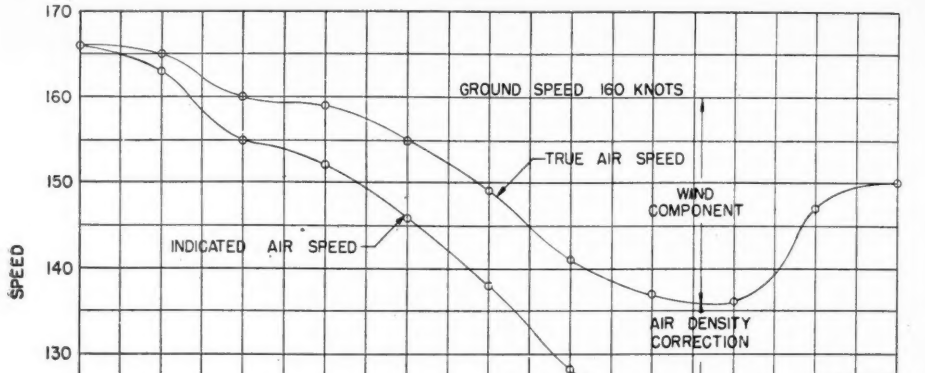


Fig. 8. Approach at constant ground speed 160 knots at Selfridge Field, 29th April 1951, 15.00 hr. Z, track 150° true.

that the 4,000 ft. *change* of altitude would be compatible with present normal descent angles in *this stage* of the approach.

(*b*) it should ideally permit some altitude spacing at the outer gate to help accommodate those aircraft which are slightly off schedule, or to which a non-standard ground speed must be assigned in virtue of special handling limitations, *e.g.* loss of motor.

These considerations should not involve a change of height of more than 5,000 ft.

The inference from all this is that the use of constant ground speed on the common straight track has the following implications:—

(*a*) it simplifies the co-ordinator's planning calculations.

(*b*) it calls for a minimum of communications —transmission on one occasion only of the specified ground speed and E.T.A.

(*c*) it involves constant power adjustment during descent.

(*d*) it may be impracticable or difficult in some aircraft types if the change of altitude is accompanied by large changes of wind and air density.

(*e*) it demands careful selection of the ground speed to minimise the possibilities of (*d*).

(*f*) if difficulties are to be avoided a change of altitude of more than 4,000 ft. to 5,000 ft. should not be called for without a special study of the associated wind and air density conditions and their effect on the corresponding air speeds.

(*g*) using this technique a group of reasonably homogeneous aircraft could normally be accepted at the outer gate with an altitude spread of about 4,000 ft. and brought to the inner gate along different glide paths set between one degree and (perhaps) 4 degrees to the horizontal.

4.9. Inference

A number of aircraft will complete a turn of some description immediately before departure from the track mesh point. In view of this and in accordance with assumption 10, it is considered that the timing accuracy on departure from there is unlikely to be better than ± 30 seconds (95 per cent. zone). In a one minute system this implies that a late aircraft and an early aircraft may take departure simultaneously, or in close

proximity. To provide for this contingency and for some mixing of fast and slow aircraft, altitude separation of successive aircraft at this point appears to be the only available solution in a single stream approach system. A logical concomitant of this altitude spacing would be provision of differential glide paths.

Under these conditions there arises the difficult question of what guiding reference can be given to the pilots to enable each to attain and maintain coincidence with his allotted dynamic niche. Flight at a specified indicated air speed, true air speed, or Mach number, has serious limitations due to the possible accumulation of small errors, particularly if combined with altitude separation. These techniques may be useful for interim solutions when homogeneous aircraft only are involved; they do not inspire confidence when heterogeneous aircraft must be handled under turbulent or severe frontal conditions.

In the general case of heterogeneous aircraft approaching at different speeds it would seem possible to attain the required precise spacing only if the pilot has continuous "go fast, go slow" directions based on up to date positional and rate information. The directions may be derived from continuous measurements of either:—

(*a*) ground speed and distance to go; or

(*b*) actual linear aircraft-to-aircraft separation and closing rates.

It thus seems necessary to provide either:—

(*a*) an E.T.A. and Ground Speed Meter, or an Off Schedule Indicator or some other form of accurate *Progress Comparator Unit* (Fig. 1); or

(*b*) blind formation keeping equipment. For this purpose airborne search radar (A.I.), suitably modified, may have application in special circumstances but the possibility of developing large oscillations and accumulating delays inclines one to prefer a system with a static reference. It will be noted also in the next section that formation keeping equipment has little application before convergence at the track mesh point, unless all aircraft are arriving from the same direction.

Attainment of one per minute (I.F.R.) requires therefore new devices and these are as yet insufficiently demonstrated in the air. It must be remembered also, that an aircraft is rather like a car with poor brakes, a slipping clutch and a limited range of speed. Even when the requisite equipment is available, it remains to be seen whether all varieties of aircraft can follow their dynamic niche under all conditions with the precision required.

Finally it is observed that reduction of the landing interval to anything substantially below one per minute does not, as a routine operation with mixed traffic, appear to be imminent or even in sight. A much higher degree of precision is required on departure from the track mesh point and similarly in every succeeding element of the system. Some improvements in aircraft speed control may be postulated. Problems of runway clearance become acute. The possibility of taking successful overshoot action in event of a sudden runway blockage (due to a crash or burst tyre) may well be reduced to a risk that is not acceptable in normal flying operations.

In making this forecast about landing rates, it is not denied that there is a possibility of bettering one per minute over *short intervals* with homogeneous (or nearly homogeneous) aircraft, given special conditions, *e.g.* a degree of surveillance which is undesirable for routine sustained operations, landing in pairs, staggered touch-downs* and so on. These solutions, while generally unsuitable for international airports, may have military applications.

5. LONGITUDINAL SPACING AT THE TRACK MESH POINT

5.1. INTRODUCTION

This section is concerned with the attainment of longitudinal spacing at the outer gate or track mesh point. Almost without exception this phase—the approach from a distance—will include:

(*a*) Descent from cruising altitude to the acceptance altitude at the track mesh point. The cruising altitude may be above 45,000 ft. with military aircraft and perhaps as high as 40,000 ft. with jet air liners. The acceptance altitude at the track mesh point will not normally exceed 10,000 ft.

(*b*) A change in the direction of motion from the *en route* track to that of the common straight track and runway in use.

*If it can be arranged fairly easily, this technique may be useful with the more general introduction of tricycle landing gear and reversing airscrews.

There may be a substantial stream of homogeneous aircraft approaching along one or more corridors as in the Berlin Air Lift in 1948; somewhat similar conditions may obtain when a wing of bombers is returning from the same target. Therefore it is useful to consider the extent to which the simplest management techniques—specified air speed and specified Mach number—can be adopted in these special circumstances. These possibilities are considered first; then follows a discussion of techniques applicable to the more general problem of meshing aircraft which are arriving from random directions.

The problem of spacing in a uni-directional stream is examined in relation to a descent from 35,000 ft. to 10,000 ft. at:

(*a*) A specified constant indicated air speed.

(*b*) A specified constant indicated Mach number.

(*c*) A specified constant true air speed.

The problem of meshing aircraft arriving from different directions and descending from 35,000 ft. to 10,000 ft. simultaneously is considered in relation to:

(*a*) Descent at a specified ground speed selected to make good the required E.T.A.

(*b*) Descent using airborne search radar equipment (*e.g.* A.I.).

(*c*) Descent along non-linear paths computed to ensure arrival at the track mesh point at a specified time.

Finally some remarks are made about time keeping on the turn or turns.

Throughout this section a one-per-minute landing system will be kept in mind as a minimum target. For this purpose arrival at the track meshing point not more than thirty seconds late or early will be considered essential. Any relaxation of this figure would postulate revision of the length of the common straight track which, as already shown, is undesirably long at 15-18 miles.

5.2. Specified Indicated Air Speed Technique in a Uni-directional Stream

This technique was used extensively in the Berlin Air Lift by the U.S.A.F. and, to a lesser extent, by the R.A.F. One of the special conditions was that the corridors had a maximum altitude of about 10,000 ft.[13]. It is necessary to consider the implications of the technique when a descent from a greater height is involved. Rate of climb/descent indicators are not especially accurate, particularly at the higher altitudes, so that a standard descent rate cannot be relied upon. Under these conditions what tolerances can be allowed in air speed without significant effect on spacing?

To obtain an approximate answer to some of these questions, consider a practical example. Two similar aircraft A and B are again sent to Selfridge Air Force Base and approach it from 35,000 ft. on a common straight track of 150 degrees. At time zero both aircraft are at 35,000 ft., spaced some six miles apart. This distance represents separation by just over one minute flying time. Both aircraft are told to descend to 10,000 ft. and level out. The intended standard air speed is 177.5 knots* and the intended rate of descent for each is 1,000 ft. per minute. Owing to imperfections in instrument calibration, aircraft management, and so on, their actual performances on the descent are:

Aircraft A

Air speed: 2½ knots high, *i.e.* 180 knots
Rate of descent: 50 ft./min. slow, *i.e.* 950

Aircraft B

Air speed: 2½ knots slow, *i.e.* 175 knots
Rate of descent: 50 ft./min. fast, *i.e.* 1,050

Figure 9 shows that, by the time they are both down to 10,000 ft., this six mile spacing has been reduced to nothing. The performance of both pilots might well be regarded as consistent with "Green Instrument Card" requirements. The military trials referred to in Section 2.9 suggest that errors in air speed will, in fact, be greater than those used in this example.

If some thought is given to the reasons for the convergence, it will become apparent that:

(*a*) Differences in air speed caused a loss of spacing of about 2.3 miles.

(*b*) Difference in the winds and air density resulted in a spacing loss of about 3.7 miles. With more extreme atmospheric lapse rates and greater variations of wind at the different altitude levels, this figure might be larger. As opposed to this a more rapid descent—at say 3,000 ft. per minute — would have considerably reduced the time of exposure of the two aircraft to the divergent conditions.

*Selected to facilitate calculations.

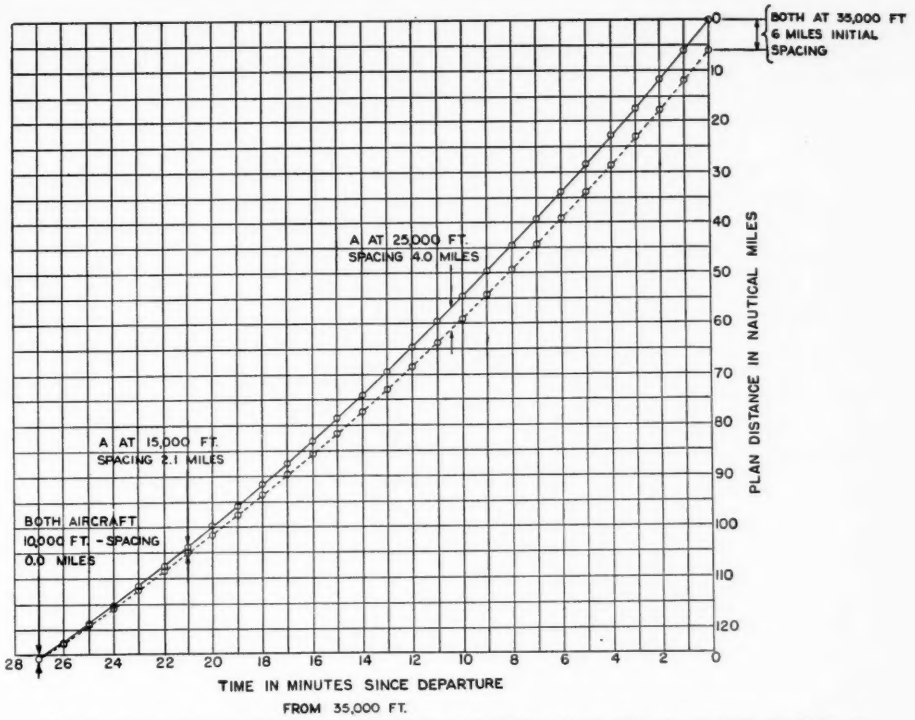


Fig. 9. Descent from 35,000 ft. to 10,000 ft. at Selfridge Field, 29th April 1951, 15.00 hr. Z, track 150° true.

——— A aircraft 180 knots I.A.S. 950 ft. per min.
- - - - - - B aircraft 175 knots I.A.S., 1,050 ft. per min. to 10,000 ft. then level.

Enough has been said to indicate that the constant air speed technique demands very precise aircraft management or frequent check of aircraft spacing by other techniques. No indication of the integrated consequence of the pilotage or instrument errors is directly available to the pilot.

Such a technique has application in specialised conditions, such as those of the Berlin operations but, without considerable buttressing, it does not show a lot of promise for development to a one minute or finer system.

5.3. Specified Mach Number Technique in a Uni-directional Stream

It has been suggested in some quarters that the constant Mach number technique might be used during descent, and its possible application to maintain spacing in a flow of homogeneous aircraft should be studied.

Communication of the aircraft's assigned flight programme is simple and the necessary Machmeters are being installed on an increasing scale. If two consecutive aircraft operate at a standard assigned Mach number, any convergence or divergence that occurs will be due to:

(*a*) The integrated effect of slight discrepancies in the actual Mach number flown. This is discussed next.

(*b*) Exposure of the two aircraft to different winds due to slight differences in rate of descent, to differences in initial or final altitudes, or to wind fluctuations. The effects of this will be similar to those discussed in 5.2 and may be serious.

The effect of slight discrepancies in the Mach number flown may be estimated roughly on the basis of a steady Mach number difference of 0.01. On a descent at 1,000 ft. per minute from 35,000 ft. to 10,000

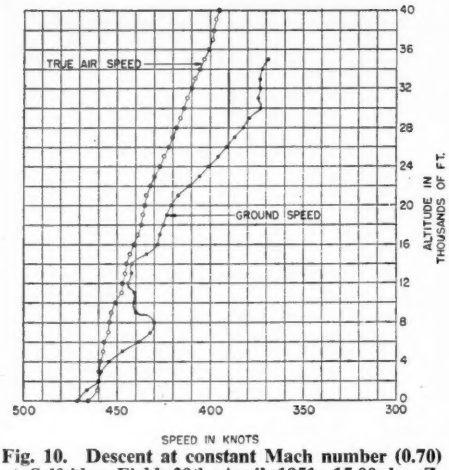


Fig. 10. Descent at constant Mach number (0.70) at Selfridge Field 29th April 1951, 15.00 hr. Z. track 330° true.

ft., the time of descent would be 25 minutes and the true air speed difference between the two aircraft would be 0.01 multiplied by mean speed of sound, or approximately 6.1 knots. The convergence or divergence resulting from this over the period of the descent is about three miles. This is equivalent, approximately, to one minute's flight at 180 knots. It follows that, if the two aircraft departed from 35,000 ft. with one minute spacing, a discrepancy of 0.01 in Mach number in flight management might result in a significant convergence by the time they arrived at 10,000 ft. (even assuming perfect synchronisation of rates of descent).

There appears to be no evidence readily available on the accuracy with which a specified Mach number can be maintained in a descent but it is scarcely likely to exceed ± 0.005 in Mach number. This would permit a convergence of one and a half miles in the conditions outlined.

Should adjacent aircraft, because of differences in their characteristics or for other reasons, necessarily descend at different Mach numbers, then the individual movement programmes must be determined for purposes of co-ordination. For this it will be necessary, in the general case, to compute ground speeds. This had been done for descent at a constant Mach number of 0.70 on track 150 degrees true at Selfridge on the chosen day. The corresponding true air speeds and ground speeds are shown in Fig. 10. The difficulties of any automatic computer in co-ordinating movements with these characteristics will be apparent. Finally as the aircraft descends air speed is increasing, which is not particularly desirable (although not necessarily unacceptable).

It is inferred that this technique, suitably supplemented by surveillance or time checks, may have at best a limited application in a homogeneous stream. Precisely controlled descent rates would be essential and for this new instruments seem desirable. Errors in flight management may become cumulative and seriously affect spacing in the system unless separate provision is made to check this. Reduction in the time of descent (by adoption of high rates of descent) would minimise the period of possible exposure to different wind systems and reduce the problems. However, from the point of view of development for general use, the technique does not show a lot of promise.

5.4. Specified True Air Speed Technique in a Uni-directional Stream

This has been discussed briefly in connection with the Common Straight Track and there is little to add. It was noted that, because of the air density correction, it has advantages over standard indicated air speed technique; compared with standard Mach number descents, it does not require quite so large a power increase at lower altitudes. The technique may have special limited application in a homogeneous, uni-directional stream of aircraft which happen to be fitted, for other purposes, with a precise true air speed meter. Because of the tight limits required in keeping to the descent time table and the necessity for additional equipment to check possible cumulative errors, it lacks the characteristics required for a general solution.

5.5. Specified Ground Speed Approach to the Track Mesh Point along Linear Omni-directional Tracks

Provided that it is practicable, this technique will enable the aircraft to arrive at the track mesh point at their planned E.T.A. regardless of wind and air density. The establishment, co-ordination, and communication of individual movement programmes is greatly facilitated if these atmospheric factors (which often vary every hour at every

altitude) can be ignored in the co-ordinator's computations.

We have assumed that the aircraft are approaching from random directions and descending from different altitudes. Because of the differences in plan position and in altitude at any moment, they may well be operating in areas of different air density and under the influence of different winds. At operating heights of 35,000 ft., winds of 100 knots and higher may be encountered. In consequence the ground speeds of two aircraft approaching the track mesh point (or outer gate) from opposite directions may differ by over 200 knots. Should there be a front running through the track mesh point, two aircraft approaching that point from different sides may be in entirely different air masses.

The first question is perhaps whether a descent at a constant ground speed is practicable with a high-speed aircraft between, say, 35,000 ft. on the distant approach and 10,000 ft. and at the track mesh point. A second question is perhaps whether this same ground speed is practicable for the rest of the approach and descent.

To examine the first question, Selfridge Field has again been selected for a constant ground speed approach on track 150 degrees at 15.00 hr. Z on the 29th April 1951. Fig. 11 shows the true air speeds and indicated air speeds (allowing for the actual winds) corresponding, at each altitude, to a ground speed of 300 knots. It will be noted that the indicated air speed must be varied from 145 knots at 35,000 ft. to 245 knots at 11,000 ft., a spread of 100 knots. Some throttle-jockeying is postulated but provided that a suitable ground speed indicator were provided, the operation seems feasible.

In the example chosen the maximum following wind (more correctly the component along the track) is approximately 40 knots. It would be possible, however, for this wind component at altitude to be, say, 80 knots. In these circumstances the range of air speed adjustment required would have been 140 knots. Again the figures from the graph cover descent from 35,000 ft. to 10,000 ft. only. Below 10,000 ft. the indicated air speed would require an even greater increment to compensate for the reduced air density correction and the weaker winds of the lower levels. Apart from the fact that it may not be possible to maintain these high indicated speeds at low altitudes, it is not particularly desirable or convenient to adopt such air speeds in the later phases of an approach. It would seem necessary, in fact, on occasions, to programme the aircraft down with two or more different ground speeds; normally one of these might cover the distant approach to the track meshing point (and the greater part of the descent) and the second the common straight track. In some wind conditions a single speed would be practicable.

It will be evident that the ground speed used must be selected with due regard to the wind and the track; otherwise the air speed called for may not be practicable at the two altitude extremes. Had the Selfridge descent studied been on the reciprocal track, 250 knots would certainly have been a better ground speed to specify; in this case the air speed variations required would have been less extensive.

From the point of view of aircraft management it would be simpler perhaps if the schedule were based, not on two ground speeds, but on a ground speed which diminished with height. This might be affected by having in the E.T.A. airborne computer some sort of cam operated by the range or height; the effect of the cam would be to call for a higher ground speed at altitude and a lesser one at low levels. Different cam settings would be necessary for different wind structures and the "setting" would have to be specified by, or known to, the movement co-ordinator. This is a complication for the ground movement co-ordinator. Practical trials of simpler equipment may be desirable in the first instance.

Another question on this technique concerns its potential accuracy. A ground speed indicator will not, in itself, necessarily ensure arrival at the correct time, as it will not be possible to keep the aircraft exactly at the desired figure. It would be possible for errors from this source and those due to instrument imperfections to be cumulative with time if the ground speed were used in isolation. In view of the widespread adoption and availability of D.M.E. a logical concomitant of the ground speed indicator would be an "off schedule indicator," or E.T.A. indicator. Two such types of equipment were referred to in Section 4.8, and one is shown schematically in Fig. 7. For an aircraft to stay in its correct dynamic niche it would be necessary for *both* E.T.A. and ground speed to be maintained at the prescribed figures.

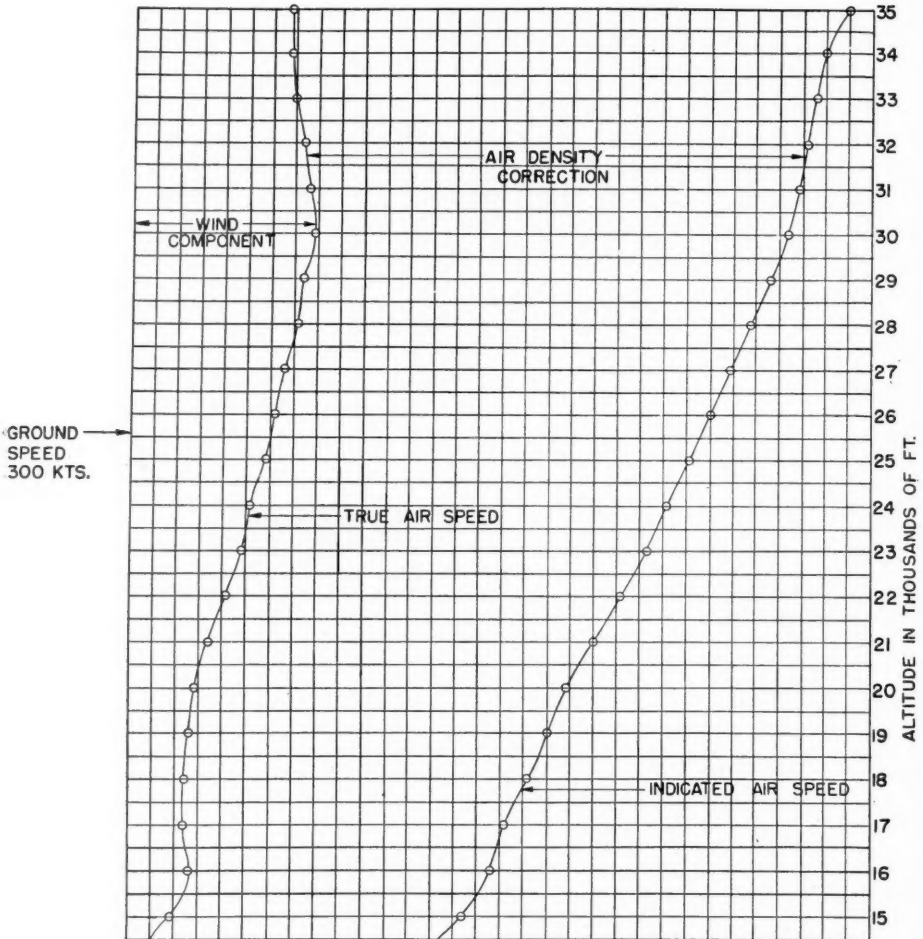


Fig. 11. Constant ground speed technique during descent at Selfridge Field, 29th April 1951, 15.00 hr. Z, track 150° true, height 35,000 ft. to 10,000 ft.

Where it is necessary to adopt two widely different ground speeds, the change from one to the other cannot be made instantaneously. If the transition is scheduled to take place at the track mesh point, this may cause temporary repercussions on plan spacing at that point. This factor, coupled with the difficulties of time keeping during the turn which precedes arrival at that point, reinforces the view that a tolerance of ± 30 seconds (95 per cent. zone) will not be easy to accomplish as aircraft leave the track mesh point.

5.6. Descent to the track mesh point using airborne search equipment

When developed and tested, this technique may well have application to the spacing problem in a homogeneous stream approaching along the same corridor. It is difficult, however, to see how it could be applied directly to space aircraft approaching the track mesh point from different directions. It might be possible to use it in conjunction with a beacon responder located at the track meshing point to permit constant ground speed approaches; this technique has already been discussed in Section 5.5.

5.7. Descent along non-linear paths of lengths calculated to ensure correct E.T.A. at the track mesh point

Some attention has been given in the U.S.A. and the U.K. to development of systems in which approach time at the track mesh point—or the runway—is regulated by varying the routeing of aircraft so as to give each the desired E.T.A. and, at the same time, maintain minimum spacing intervals at all times. The computation may be done in the air, or on the ground. It is necessary to examine these systems from the point of view of programme computation, communication and flight management.

The object is to plan for each aircraft a flight programme which will bring it into juxtaposition with a selected dynamic block of space moving along the final straight approach track. This is similar to the defence fighter interception problem except that the target is flying on a straight track along the prolongation of the runway and its speed is known. The fact that the target track is linear and accurately known is a simplification, but among the complicating factors are:

(*a*) Interception must be made on a pursuit course.

(*b*) The intercepting aircraft cannot, in general, be programmed on the basis of a constant ground speed owing to its changing height.

(*c*) The assumption of an equal and constant wind for both target and interceptor—sometimes used in the air defence problem—cannot be made.

(*d*) Other aircraft are required to carry out similar interceptions in the same area almost simultaneously. The paths and schedules selected for each must be co-ordinated and safe spacing always maintained.

(*e*) At the point of interception, the speed of the interceptor should be equal to the speed of the target, that is, of the dynamic niche; and its speed should be closely stabilised to prevent over-shooting.

Great advances have been made in the development of digital computers, magnetic storage drums, and so on; in view of these, comment would be welcomed on the possibility of producing the computer required. By analogy with other multi-interception computers—contemplated and otherwise—it seems that the unit necessary at each major terminal might conceivably involve some four or five thousand valves (tubes). At the moment it is the author's impression that the techniques necessary and such equipment as becomes available may well be retained for purely military use for some years. 1960 is perhaps the earliest date by which such equipment could become available to civil agencies in a proven form.

It is possible to simplify the computation if special conditions or procedures are imposed on all aircraft. If, for example, the "interception" is made at a standard speed, in *level flight after descent*, the problem is much easier. As an example of ingenious simplification, reference is made to the Equidistant Zone Chart described by Coulson and Burgmann[14] of Australia and used in conjunction with an orbiting system. This system in its simplest application is similar to others which assume that the time taken to fly any prescribed pattern, or portion of a pattern, is proportional to the distance. This will be true only if it is possible to fly at constant ground speed on *curved* courses.

There is no indication that the equipment necessary for this is likely to become generally available in the next few years. Unless aircraft are to be confined for some considerable time to a constant (standard) altitude after completing their descent—and this usually means more fuel—it does seem necessary to take account of wind variation with height and its varied effect on different headings; in other words it seems necessary to work in terms of ground speed. Simplified methods of computation may have application in special cases where some of the variables are eliminated, but it seems likely that there will be penalties in either flexibility or in development potential towards a fine spacing system.

Let it be assumed that the computer problem has been solved and a device is available in the control tower to specify, for each aircraft, a discrete course of action which will bring it to the track mesh point in coincidence with its allotted niche. There still appear to be problems in connection with either communications or flight management. From the point of view of communications, the movement programmes may be passed to individual aircraft in one of two ways:—

(*a*) only executive flight instructions or steering instructions may be transmitted, that is, instructions which tell the aircraft to go left or right, to go up or down. Such a "command" system—as it is often called—may be practicable from the communication aspect but there are usually some serious flight management problems in connection with track keeping and time keeping on curved paths. These are discussed in Section 5.8.

(*b*) the allotted tracks and altitude paths may be transmitted to the aircraft, perhaps with time schedules. Equipment such as the American Sperry Track Follower might then be utilised to follow them. If the interception tracks and *schedules* necessary are highly complex, something like airborne facsimile or teletype may be necessary. It seems dangerous to assume that such devices could be general fitment before, say, 1958. In any case such communication equipment seems a little complex for the smaller categories of transport and military aircraft.

The deduction of this sub-section is that automatic sequencing systems based on allocation of non-linear flight paths are still too far ahead to provide a basis for a traffic system in 1955-1965.

5.8. Timekeeping and Spacing in Turns of Small Radius

It has already been noted that, in general, approach to the track mesh point will include a change in the direction of motion from the *en route* track to that of the common straight track leading on to the runway. This change of direction in the majority of current and proposed traffic systems is accomplished along paths the radius of curvature of which is usually less than 15 miles. More commonly "rate one" turns, or orbits of seven to 10 miles radius, are mentioned. Fig. 15 shows a typical proposal using lateral separation as well as longitudinal. If a precise arrival is required at the track mesh point, it is necessary to consider what schedule keeping accuracy is feasible during these turns and at their conclusion.

Were it possible to fly the curve accurately at a constant ground speed, no particular problem would arise. Unfortunately, aircraft are usually designed to be stable in linear flight with mainplanes horizontal; even with an ideal guidance system, it is not especially easy to make them follow a particular path of high curvature. While this may be open to some discussion, there will be less contention about the possibility of flying on small radii orbits or semi-orbits at constant ground speed. It is doubtful whether any direct-reading ground speed indicator, which will function accurately on curved tracks and in areas of turbulence, will become generally available to civil aviation before the end of this decade.

Even if such an indicator were available, there is still a real problem in aircraft management in a wind of, say, 40 knots; an aircraft flying a semi-orbit and seeking to maintain constant ground speed would be required to adjust the air speed by 80 knots (that is, from plus 40 knots downwind to minus 40 knots upwind) during the 180° turn. To do this accurately in a small distance is itself a problem. Some improvements in ability to govern aircraft speed may well be postulated.

In view of these difficulties which arise when constant ground speed schedule is attempted, many suggested systems programme the necessary changes of direction on a basis of constant air speed and/or

constant rate of turn. Downes[10] in Australia has given an indication of the scatter in time that might be expected in completing a 90° (approximate) change of direction using this technique. His tests are based on 96 actual flights with 37 pilots in Dakota (C-47) aircraft. His analysis of results shows briefly:—

(*a*) Initial turn (from a straight track on to an orbit)

Theoretical duration at rate one	0.47 min.
Mean time taken for turn	0.8 min.
Deviation from mean not exceeded by 90 per cent.	0.3 min.

(*b*) Final turn (from an orbit on to the final approach)

Theoretical duration at rate one	0.53 min.
Mean time of actual turn	0.7 min.
Deviation from mean not exceeded by 90 per cent.	0.3 min.

The data suggests that, with current techniques, the time scatter which arises from a 90° turn is about 0.3 minutes or 18 seconds for the 90 per cent. zone only. With mixed aircraft types this may well increase.

The deductions appear to be that for the next five to ten years some departures from desired time schedules will be likely during the change of direction. As this will often necessarily exceed 90° it would seem dangerous to assume that the 90 per cent. time scatter will be less than ± 20 seconds until completely new techniques become available. It is suggested that, in the interim, reduction of time spent on turns to a minimum is desirable to eliminate accumulation of these off-schedule errors; alternatively, any curved paths must be followed by an adequate straight run or other means to permit correction of accumulated timing errors.

5.9. Inference

In the general case of omni-directional approaches, correct meshing demands arrival at the planned moment. There is at present little sign of equipment to permit accurate schedule keeping on curved tracks; it seems best, therefore, to rely on linear approaches and to keep turns to a minimum. E.T.A. indicators or Off-Schedule indicators for use on straight tracks could be produced fairly easily. Although these are not without their problems, it seems likely that they would contribute to accurate timing at the track mesh point. Such a device would be useful both to aircraft making a direct approach and to those coming from a stack. It would also be useful for the maintenance of spacing on the final straight approach.

It is nevertheless quite clear that it will be extremely difficult to ensure arrival at, and correct departure from, the track mesh point with a 95 per cent. precision of ± 30 seconds. New equipment not yet demonstrated seems essential; it may also prove necessary to design into aircraft the means for better regulation of the forward speed. The necessity for highly accurate navigation systems has been stressed in other papers[15] and is supported by the author.

On the basis of the examination in Sections 4 and 5, it seems that while a one-per-minute longitudinal separation may be achieved occasionally under selected conditions, it will not be easy in the general case. This is not surprising if one considers that the minimum time interval observed between London Tube trains is, generally speaking, ninety seconds.

If an acceptance capacity of more than 50 or 60 per hour is required the flow permitted by longitudinal spacing in a single stream will not therefore suffice. Other methods of increasing the flow must be sought.

6. Lateral Spacing

6.1. Introduction

Lateral spacing has many attractions. Instead of transmitting a movement timetable, it is necessary to transmit only a lane number, thus cutting down communications. The movement of each aircraft into its lane helps the surveillance unit with the identification problem. Tracking or lane deviation indicators are already standard items with a number of the navigation systems; moreover, these instruments give the pilot up-to-date information based on the accumulated displacement so that neither the pilot nor the movement co-ordinator have to worry about the possible effects of error accumulation—which caused some concern in longitudinal spacing. Provided that sufficient lanes or corridors are available, movement co-ordination is extremely easy with relative positions easily contemplated and displayed.

These advantages and conveniences, however, are largely negatived if the corridors or lanes must eventually merge on to a single runway, for the capacity of the entire system

is then reduced to the acceptance rate of the single runway and the associated common approach track. However brief this phase may be, the system is thereby reverted to longitudinal spacing with all its limitations and problems. If an attempt is made to minimise this phase by keeping the corridors separate until the latest possible moment, little is gained because there immediately arises the problem of meshing the aircraft as they emerge from their final turn—with little opportunity for simultaneous altitude separation.

The use of lateral separation right on to the airfield would postulate, of course, provision of parallel runways. There are immediate and serious implications affecting airfield extent, cost, design and operation. The basic consideration underlying all these questions is how close can such lanes and runways be placed.

As an indication of British civil aviation policy in this connection, a review is made of the relevant portions of the report of the Layout Panel for London Airport (May 1946). This is followed by some observations on tracking accuracy as demonstrated since that report was compiled and a discussion of the separation necessary for parallel approach tracks in the period 1955-1965.

The examination of longitudinal spacing was theoretical. Fortunately, there is available quite a lot of experimental evidence on tracking accuracy. Whereas, in the preceding two sections, purely hypothetical errorless position fixing systems were assumed to be available, the conclusions here are derived largely from results obtained with existing equipment.

Lateral spacing might be associated with a convergent or divergent runway configuration but there does not appear to be much enthusiasm for such systems, perhaps because of the over-shoot problems.

6.2. Report of London Airport Layout Panel

In 1946 the London Airport Layout Panel studied runway separation requirements for:—

(*a*) simultaneous landings.

(*b*) simultaneous landings and take-offs.

(*c*) staggered runways.

The agreed figure given in Appendix B of the Panel's report[16] for separation of runways for simultaneous landings in instrument conditions is "at least 6,000 ft." In this connection the Panel noted in Section 9 that:—

> "a separation of two and a quarter miles, at a distance of ten miles from the airport would at present be needed for simultaneous and independent movement along adjacent approaches in instrument conditions. This is practicable only with divergent runways . . . We thought, however, that it would be desirable to maintain a separation of about 6,000 ft. since, although this is insufficient for simultaneous instrument approaches at present, it may be adequate in future."

In the final plan produced by the Panel, this separation is exceeded on the most-used runways but a reduction to about 4,500 ft. had to be accepted with some less important runways.

With staggered secondary runways, a separation of 2,500 ft. was observed, this being the "minimum separation between two parallel runways when landings on one and take-offs on the other are likely to take place simultaneously."

The Panel noted the lack of reliable practical data on this separation problem and urged that practical tests should be made as soon as possible. The report on such tests, if they have been made, is not known to the author. It is possible however to adduce some data on the basic question—tracking accuracy. This is considered in respect of linear or low curvature flight first and secondly (rather more briefly) in respect to curved paths.

6.3. Tracking Accuracy—Linear Flight

Quite a lot of evidence could be adduced in connection with the performance of aircraft endeavouring to track along a radio-defined datum, but only a few of the available reports will be mentioned here. In some of the trials referred to, the tracking datum was a hyperbola but in these cases the reference is to the substantially straight portions only.

In the second half of 1946, R.A.F. Transport Command Development Unit at Brize Norton made a preliminary evaluation of the Australian Multi-Track Radar Range, using Dakota (C-47) aircraft and checking

tracking accuracy along the airfield approaches. The report[17] states that, "under normal operating conditions, approach accuracies within plus or minus about fifty yards from the runway centre line would be reasonably expected." The aircraft were flown manually using a standard I.L.S. cross-pointer indicator. Photographic records of limited precision were used for checking the actual track.

In 1950, Downes further investigated the tracking accuracy of the Multi-Track Range and some Australian D.M.E. His report[10] is more comprehensive than that of R.A.F. Transport Command and is based on an analysis of 96 approaches made by a total of 37 pilots. The approach to the "localiser" line was made from an airfield orbital path so that a change of direction of about 90° was required in turning from the orbit on to the final straight track. Downes analysed the figures pertaining to the final approach (that is the run between the seven mile range and the airport boundary) under two headings:—

(*a*) accuracy including departures due to the initial over-shoot. For 90 per cent. of 51 approaches this departure did not exceed ± 0.5 miles from the mean value.

(*b*) accuracy *ex*cluding the initial over-shoot. In 90 per cent. of the approaches the maximum departure did not exceed ± 0.2 miles from the mean value.

From (*b*) it looks as though 90 per cent. of these 37 pilots can be kept, without undue difficulty, within a lane 0.4 miles wide (say, about 800 yards).

The All Weather Flying Division of the United States Air Force made a series of tests in 1948-9 on the "flyability" of various instrument approach systems, notably S.C.S.51, G.C.A. and 2,600 mc. Micro-wave I.L.S. The results of these tests are "restricted." It is, however, in order to mention that, during the last mile preceding touch-down, 95 per cent. of the approaches with all three systems were enclosed within a space of slightly less than 400 ft. in width. With automatic pilots in use on certain of the systems considerably less deviation from the mean path was evident. The tracking theodolites used for checking results required C.A.V.U. weather conditions and the pilots may have been more proficient than the normal average, but the results are an excellent indication of the precision that is possible with existing equipment. Closer to the touch-down much greater precision was achieved.

This sort of accuracy is not confined to the areas served by a localiser. Some interesting figures are available in a report[18] prepared by the Ministry of Civil Aviation, in collaboration with other United Kingdom governmental agencies, on tests in 1948 of the British guidance system, Gee Mark 3. The report indicates that the standard deviation of an aircraft from a Gee lattice line appeared to be 0.0051 Gee units (as compared with 0.0115 for the wartime Gee Mark 2). To interpret this it is necessary to take into account the lattice spacing which, for some 5 runs (129 plots approximately) was about 120 yards. This is equivalent to a 95 per cent. error of 240 yards.

At this time, the author has available for reference only extracts from the report but these also include a table showing the Gee tracking accuracy near seven airfields covered by the British Eastern Gee claim (1948). The average 95 per cent. tracking error is given as 340 yards.

It is possible to adduce even better figures for tracking accuracy given special guidance equipment such as Shoran and Oboe. Such data have been given in various air survey lectures (*See*, for example, Ref. 22). In all such papers it is necessary to distinguish between the accuracy with which the track was recorded and the accuracy with which an intended path was flown. From a review of all available data made by the author in 1947 while serving in the Directorate of Operational Requirements, Air Ministry, an actual flight accuracy of ± 200 yards (50 per cent. zone) seemed feasible at about 100 miles range using G.H. Mark II equipment. With Oboe even more precise tracking was achieved. In obtaining these results specially selected pilots were usually available but it is nevertheless useful to note the standard of practical accomplishment which is already on record.

These data are summarised—somewhat imperfectly—in Table III. The results quoted are *not comparable* one to another and each should be considered in relation to the test conditions which obtained. Nevertheless the table does demonstrate that a relatively high standard of tracking accuracy has been demonstrated *in the air*. The advent of improved steering indicators utilising rate components (such as the Zero Reader, the U.S.A.F. ID 249, and others), the

probable availability of improved localisers and the increasing utilisation of auto-controls all suggest that even better tracking performance can be expected in 1955-65.

One purpose of this paper is to suggest that this positive achievement in tracking accuracy be exploited by setting up parallel streams to increase the flow of aircraft through the congested approach zone at important terminals. Before considering how this might be done a few remarks are in place regarding tracking accuracy on curved paths.

6.4. Tracking accuracy—non-linear flight

Downes[10] also obtained data as to the deviations of aircraft when flying along a curve of eight miles radius. From a study of almost 100 orbital paths at Sydney (Australia), it was found that in 90 per cent. of approaches the maximum departure from the orbit did not differ by more than ± 0.8 miles from the mean value. Although the majority of the maximum departures occurred within the first 90° of the orbit, there was no significant increase in accuracy of flight thereafter.

In his summary Downes points out that the maximum departures from the tracks laid down (linear and otherwise) for his suggested approach procedure occurred during orbiting. In this phase the average track was 0.2 mile inside the nominal orbit.

During the evaluation of the Omni-Bearing Distance Navigation System in U.S.A. some attempts were made to fly small orbits but the information available refers to "way point orbits." As far as these are concerned it will be sufficient to quote an extract from the final summary report[19] by Airborne Instruments Laboratory, October 1950 which states:—

> "Way point orbits, particularly those with radii less than six miles, could be flown only with difficulty. This arose through an inability of the autopilot to follow data for small radii orbits and, when far from an O.B.D. facility . . . (through other factor)."

It might be possible to produce other data under this heading but it would be difficult to collate them and arrive at generalisations applicable to 95 per cent. of aircraft because of:—

(*a*) differences in the stability of different aircraft types during turns. Results obtained with Dakota (C-47) aircraft may bear no relation to those obtainable with a Boeing B-47 (Stratojet Bomber).

(*b*) differences in auto-pilot performance.

(*c*) differences in the quality of the guidance information.

Until more varied and representative data is available it seems wise to assume that:—

(*a*) precise tracking on curves of radius less than eight to ten miles may prove difficult in some aircraft. (This means that different aircraft flying the curve do not all traverse the same distance.)

(*b*) time keeping while tracking on such curves may accordingly be somewhat

TABLE III

Recorded tracking accuracy (manual flight)

Date	*Reporting agency*	*Guidance system*	*Range in miles*	*Accuracy*	*Remarks*
1946	R.A.F. Transport Command	Multi-Track Range	Over runway	50 yd.*	Ref. 17
1950	C.S.I.R., Australia	Multi-Track Range	1-6	400 yd., 90 per cent.	Ref. 10
1948-9	All Weather Flying Divn., U.S.A.F.	G.C.A., I.L.S. and 2,600 Mc. I.L.S.	About 1	±200 ft., 95 per cent.	Reference restricted
1948	Civil Aviation, U.K.	Gee Mk. III	Over 15	240 yd., 95 per cent.	Ref. 18
1946-9	R.A.F. Survey Squadrons	G.H. Mk. II	Over 15	200 yd., 50 per cent.	Selected pilots
World War II	R.A.F. Path-finders and T.R.E.	Oboe	Over 15	Better than 200 yd.*	Selected pilots

*Number or percentage of occasions not known.

inaccurate unless continuous or very frequent indication of the cumulative departure from schedule is available.

Trials of the Sperry Track Follower are at present under way within the All Weather Flying Division (U.S.A.F.) and the results may well provide valuable information on this subject generally.

6.5. Factors Affecting Lane Separation Distances

It was suggested earlier that the success which has been achieved in linear tracking should be exploited to increase the flow of aircraft through the congested approach area. The most serious congestion arises perhaps in the area of the track mesh point and it is necessary to consider what separation would be practicable for parallel (or roughly parallel) lanes between that point and the end of the landing run. The same question arises in relation to congested air routes prior to arrival at the track mesh point but, away from the terminal, more space is available to permit larger altitude and larger lateral separations. As the various lanes descend to the airport, all aircraft must reach a common altitude—(that of the field)—while lateral spacing of runways must be minimised. For these reasons lateral spacing will be considered only in relation to the critical zone from the track mesh point onward.

For the purposes of this discussion it is convenient to assume that parallel tracks are used. The advantages of slight degrees of radial divergence away from the airfield—as is possible with a short base line hyperbolic system—will be apparent. However the immediate problem is the possible advantage of lateral spacing *vis-a-vis* longitudinal spacing; in general any conclusions arrived at in respect of parallel streams will be largely valid with a low curvature hyperbolic system.

The exact spacing of any pair of parallel approach tracks and runways for use in 1955-65 will depend on:—

(*a*) accuracy and/or resolution of the guidance signals available in that decade.

(*b*) efficiency with which these signals can be used, that is the efficiency of flight management.

(*c*) the degree of collision risk that can be accepted and covered by other methods (normally by radar surveillance).

Of these, the first two factors have been considered together in Sections 6.3 and 6.4.

With regard to the degree of collision risk, the lane can be made wide enough to contain 99 per cent. of the departures, or 95 per cent. of them, or 90 per cent. or any other portion of the stream. Assuming continuous guidance information and aircraft fully responsive to them, Caradoc Williams in 1948 graphed the lateral width of the lane against the fix accuracy of the navigational system. For convenience his diagram is reproduced, with minor adjustments, in Fig. 12. From this a guidance system with an accuracy of 220 yards (50 per cent. zone) should normally keep 90 per cent. of aircraft utilising it within a lane 1,000 yards wide. It has already been assumed that a system which will handle 90 per cent. of the aircraft would be initially acceptable, with supplementary surveillance, provided that it would cater with development for 95 per cent. of the traffic. It is interesting to compare this figure with the practical results reported already and listed in Table III.

6.6. Possible Lane Spacing Distance

It will be apparent that, for parallel lanes, precise track datums must be established. In the area which is being considered—the last 15-20 miles of the approach—the guidance system is currently, in most instances, that provided by Instrument Landing System Localisers and/or Precision Approach Radar (G.C.A.). Unfortunately the lateral positioning accuracy of these equipments decreases with range and presumably the same can be said of any single point angular measuring system used on its own. To cover, adequately, the area from the track mesh point to touch-down, the range involved on the basis of earlier assumptions would be 15 to 18 miles—say, 20 miles. The accuracy necessary for 1,000 yard lanes corresponds at this range to a bearing accuracy of $\pm$ 0.375 degrees (50 per cent.); in other words the beam must be sufficiently well defined and flyable to retain 50 per cent. of the aircraft within a sector of 0.75 degrees. If the common straight track is only 15 miles long the corresponding requirement is for a beam which will keep 50 per cent. of the aircraft using it within a sector of one degree.

Looking at the currently available guidance systems it can be noted that U.S.A.F. Precision Approach Radar has a specified

beam width of only 0.6 degrees; the present operating range however is normally below twenty miles. Recent I.L.S. localisers such as the U.S.A.F. AN/MRN-7 have the necessary range and a precision of a higher order than the old S.C.S.51. The specifications for these are not available but, as the equipments stand, the 50 per cent. sector is almost certainly somewhat broader than our figure.

What is required, however, is not the theoretical accuracy but the actual scatter in representative flights. If the I.L.S. localiser and Precision Approach Radar (G.C.A.) do not, in themselves, permit lanes of width less than, say, 1,000 yards it may still be possible to adopt this spacing by:

(*a*) Arranging for some vertical separation between adjacent tracks at the outer end.

(*b*) In the case of I.L.S. localisers, by using a finer beam sited, perhaps, slightly upwind of the runway.

(*c*) A combination of both these expedients.

As these existing final approach guidance systems (G.C.A. and I.L.S.) were not designed to facilitate lateral spacing, it can scarcely be expected that they will be entirely suitable as they stand. The Australia Multi-Track Range or Gee Track Guides may well be more adaptable. Leaving particular systems, however, it is suggested that the state of the electronic art is such that guidance lanes with an accuracy suitable for 1,000 yard spacing (90 per cent.) or better could be in production in a very few years. This would be followed by an introductory period which raises the problem of transition from the present approach system to a parallel approach system.

For several years at least there will be a diversity of guidance and approach systems in use and these will have varying accuracies. These accuracies affect the possible runway approach lane spacings. If lateral spacing is adopted it would seem logical to:

(*a*) Adopt different separations as between different pairs of runways on any one airfield, according to the accuracy of the associated approach systems.

(*b*) Provide one runway rather apart from the others to accommodate the ten or twenty per cent. of aircraft which have the largest probable track departures.

(*c*) Group aircraft, to some extent, not only with regard to their approach speeds, but their track keeping efficiencies. The more efficient track keepers would be eligible for routeing not only to the widely separated runways but also to the closely spaced ones (thus reducing their prospect of terminal delay).

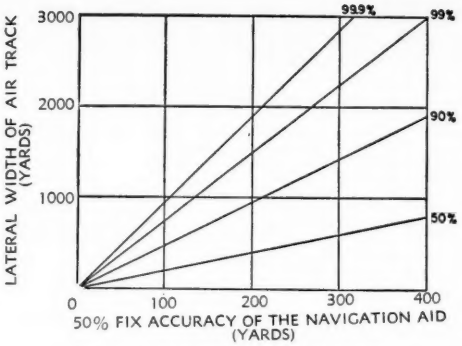


Fig. 12. Lateral width of air tracks.

(*d*) Utilise some altitude separation at the track mesh point to counter the effect of large track departures occurring at the initial "turn on."

The implications on airfield layout must now be considered.

6.7. Airfield and Aircraft Implications

Provision of any number of parallel runways on a single airfield, civil or military, immediately suggests problems in connection with:

(*a*) The area of paving required and the cost thereof.

(*b*) Possible increase in the size of the field.

(*c*) Interference by taxying aircraft and vehicles with the runways in use.

With regard to the cost of additional paving, the important question is the cost of *paving required per aircraft movement*. Provided that each runway is used to capacity, lateral spacing should not cost any more (perhaps less) than longitudinal spacing with its inevitable airport duplication; for the moment there do not seem to be any very cogent reasons why the adoption of lateral spacing should seriously prejudice simultaneous use of longitudinal spacing. Any advances in either technique can surely be fully exploited.

Nevertheless there will be idle runways in periods of low traffic density and

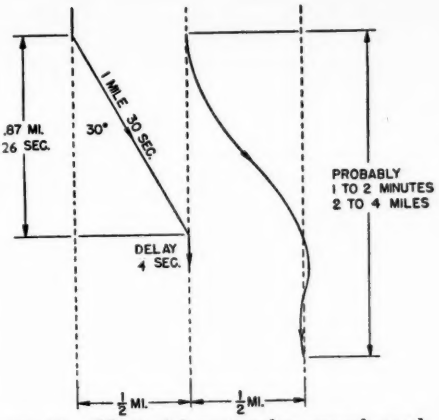


Fig. 13. Effect of lane transfer, ground speed 120 knots.

undoubtedly additional initial costs per airfield are postulated. These additional costs will be considerably reduced if the conventional three axis airfield can be replaced by a two axis airfield. In England Ayers[21] (September 1949) has commented on this question as follows:

> "The average two-runway layout usability in this country (England) is usually below 90 per cent. with a 15 m.p.h. cross wind component, but increases to approximately 97 per cent. if the cross wind acceptable is raised to 20 m.p.h. . . . To accept 20 m.p.h. cross winds the design demand is inherent directional stability on the ground . . . given only by tricycle undercarriages, and the strength to accept, with a safety margin, the side thrust imposed by a possible 40 m.p.h. gust."

The adoption of a new airworthiness stress requirement to cover these undercarriage side loads would involve some increase in weight, and perhaps adoption of some form of castoring landing gear. However, if this cross wind problem can be solved without too much cost, parallel runway airfields certainly become much less costly. If, as the author maintains, more runways mean less average and less potential delay, the fuel margin can be reduced and that extra undercarriage weight may well be worthwhile. An extra 100 lb. undercarriage weight would correspond to about 13 gallons of fuel—and that does not keep an aircraft aloft for very long. It is worth mentioning too, that a two axis system reduces the frequency of delays arising from changes of wind and landing direction.

With regard to possible increase in the size of airfields, three runways spaced 1,000 yards apart require very little more territory—if any—than two runways 2,000 yards apart. If 800 yard spacing can be adopted, four and five parallel runways seem possible with not too much increase in the area of some of the principal international airports.

To consider now the third airfield difficulty, that of surface movement. The introduction of additional runways does certainly introduce ground traffic and reception problems. The author is not competent to consider this in any detail but, on a two axis runway system, a solution does not appear impossible. Undoubtedly some compromise would be involved to the present principle of a single central terminal building where increasing congestion is already developing. Some decentralisation of reception and passenger handling seems desirable not only to relieve congestion but in some countries also as a measure to reduce vulnerability to air or missile attack. Decentralisation of reception facilities, after all, is common practice at shipping and train terminals. At large international airports the use of subways (underpasses) for passenger and vehicular traffic on an increasing scale would seem to be postulated. Under low visibility conditions such a system is likely to prove more efficient than surface movement.

An indication of possible runway layout is shown in Fig. 14. It must be emphasised that this diagram represents first thoughts only and undoubtedly more mature study and the experimental trials (which are essential) would give rise to considerable revision.

6.8. Miscellaneous Advantages of Parallel Runways

The adoption of three or more parallel runways and approach lanes brings advantages as well as problems. Among the advantages are:—

(*a*) One runway can be released for repair and/or maintenance without drastic curtailment of handling capacity. Air Commodore Merer[13] stressed the importance of this in his paper on the Berlin Air Lift.

(*b*) It reduces the problems arising from a blocked runway.

(*c*) It makes possible some grouping of approaching aircraft into streams which are sensibly homogeneous from the point of view of speed. Such homogeneity increases the potential rate of acceptance on any one runway.

(*d*) It facilitates the handling of air traffic using different approach aids and consequently the transition from one aid to another.

(*e*) It increases the potential acceptance rate for each stream. By means of transfer from one lane to another, unpredicted bunching in one stream can be alleviated by transfer to gaps in any adjacent stream.

In connection with (*e*), it is interesting to examine Fig. 13 which shows the effect on time schedules if one aircraft is transferred (by a 30° change of track) to a parallel lane one separation distance away. The diagram is based on half a mile separation but the figures can be adjusted for any other spacing. Even with a one mile separation (two lanes in Fig. 13), the distance covered in the transfer is small compared with the length of the common straight track as already predicated, that is 15-18 miles. The delay effected by the transfer—although undoubtedly subject to some variation—is small and reasonably predictable. In so far as a simultaneous coincidence of "bunching" in all lanes is much less probable than its occurrence in

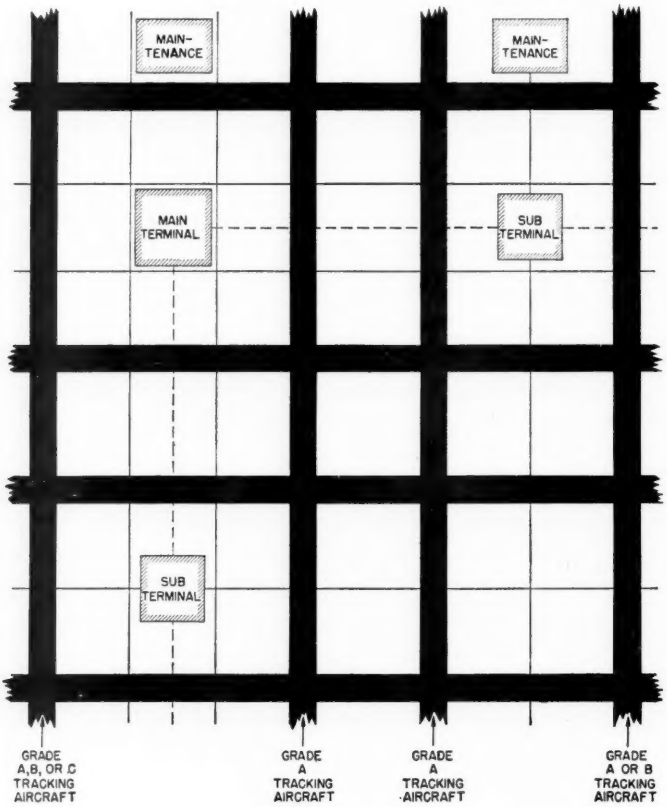


Fig. 14. Two axis airfield (schematic only—not to scale).

one, the adoption of a parallel approach system and intelligent use of lane reassignment should materially assist in converting random longitudinal spacing in several lanes to acceptable spacings at the runway—without any lengthy communications or involved calculations. On the ground any four adjacent turnstiles have a better flow and higher aggregate capacity than four isolated ones. It may well be the same in the air.

6.9. Inference

The standard with which aircraft can track along a suitably designed radio datum line is extremely high provided that it is substantially straight. Practical results which are quoted suggest that in the 15 mile zone preceding touch-down, parallel corridors could be established with centres perhaps 1,000 yards apart. It appears to be well within the state of the electronic art to provide the necessary guidance which would lead aircraft on to parallel runways. Consequential surface movement problems suggest re-design of airfields on a two axis basis. This in turn postulates new aircraft design requirements with respect to cross wind landing characteristics. From this cursory study these changes may however be well worth while. A very real increase in landing capacity seems possible and, by reducing the fuel reserve necessary, may more than compensate for some increase in aircraft structural weight.

7. THE NAVIGATION SYSTEM

7.1. Introduction

This section comprises a few miscellaneous remarks, not a detailed examination, of the navigation requirements. To some extent it reiterates points already made. It is assumed that longitudinal spacing is based on a normal navigation system and not on A.I. or blind formation keeping equipment.

7.2. Smoothing the Arrival Rate

It has been implicit throughout this paper that the problem of random arrival rates should be minimised by the following techniques:—

(*a*) by designing terminal facilities so that they have a large reserve handling capacity—as recommended by Bowen and Piercey[7].

(*b*) by varying aircraft approach speeds to introduce some regularity into the arrival times at the track mesh point. It is normally possible to vary aircraft speed to *some* extent (particularly during descent) without a very detrimental effect on the total fuel consumed during the journey and this flexibility should be fully exploited.

The latter of these has implications on the range and accuracy of the navigation facilities.

If 20 aircraft indicate their intention to arrive within a period of ten minutes, say between 10.05 and 10.15 hours, it will normally help if their E.T.A.s can be redistributed over 20 minutes so that the terminal has to handle one per minute. This might be done by accelerating the first so that his E.T.A. is advanced by five minutes to 10.00, advancing the second to 10.01, etc., and retarding the last by five minutes so that his E.T.A. becomes 10.20 (instead of 10.15). Any such action implies the existence of a precise navigation aid for a reasonable distance from the terminal and some idea of the range required can be inferred from Fig. 5.

Considering the case of the aircraft which has to be accelerated by five minutes and assuming it to be travelling at 300 knots, a speed increase of $V/5$ will allow it to gain one minute in 30 miles. To recover five minutes it will therefore need 150 miles. If the initial speed is 400 knots, the corresponding distance is 200 miles. Provided therefore that the speed variation of $V/5$ does not have a significant effect on miles per lb. of fuel during this *descent* phase, a navigation system of adequate range and accuracy may well permit redistribution of the 20 arrivals over a 20 minute period.

To pursue the matter further a detailed study is necessary of fuel consumption characteristics of future aircraft during descent. This cannot be done here but it is noteworthy that, in some jet aircraft at least, the fast high level approach followed by a steep descent is not as economical as a slow gradual descent taking a longer time. Provided that there is some flexibility in the speed during this descent, it should certainly be exploited to reduce the terminal problem.

This then is a factor affecting the range of the terminal navigation system. In considering the range performance of any particular device in relation to the requirement, it is

important to remember that we are interested in results obtainable in 95 per cent. of the approaches—and not the 50 per cent. zone. For this reason the range advantages of navigation systems operating at frequencies below 100 mc./sec. may merit careful study before deciding on any long term solution.

Whether this approach is agreed or not, it must be remembered that the timing accuracy of individual aircraft when it emerges from present long range navigation aid systems is unlikely to be better than three or four minutes (95 per cent. zone). There is some evidence which cannot be disclosed in detail that present performance is well below this. Apart from any question of accelerating the arrival time, adequate range must be provided to permit progress checks and the correction of small deviations from schedule.

7.3. Longitudinal Progress Information

If heterogeneous aircraft coming from different directions are to be spaced longitudinally in a single closely packed stream so that they land at one minute intervals, it seems necessary to refine the timing accuracy to $\pm$ 30 seconds by the time the aircraft take their departure from the track mesh point along the common straight track. Along this straight run, further timing refinement is necessary. To effect all this progressive timing—or spacing—refinement, the device most necessary is a *Progress Comparator Unit*. The functions of this equipment would be:—

(a) to show the pilot his accumulated schedule (or spacing error) continuously while descending before his arrival at the track mesh point—and to show him how to correct that error. It would serve the same purpose again on the final straight track. This implies a highly accurate navigation system or spacing monitor, probably with longitudinal rate information, plus a *comparator* unit.

(*b*) to keep the aircraft on schedule (or correctly spaced) when affecting the change(s) of course necessary to arrive on the common straight track with the correct velocity. This equipment serves the same purpose as that in (*a*) above but it would function on non-linear tracks. It is however much less important than (*a*).

The author is not aware of any solution to (*b*). For (*a*) reference has been made to

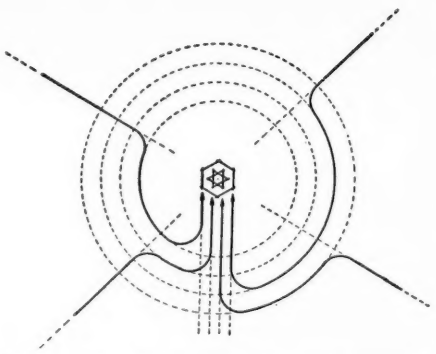


Fig. 15. Parallel runways with orbit approach.

"Off-Schedule Computers" and "Off-Schedule Controllers" under development and based on the constant ground speed technique. Once these are available in proven form, experimental progress can certainly be made and the necessity for the non-linear version more correctly evaluated. As has already been indicated, it will probably be necessary to programme aircraft during the descent on diminishing rather than a single constant ground speed.

Pending a device to maintain schedule or spacing during turns, the degree of punctuality or spacing accuracy sought prior to the track mesh point should be comparable only with that which can be maintained throughout the final turn.

7.4. Deployment of Navigation Aids

The use of D.M.E. Beacons, in conjunction with Off-Schedule Indicators or other devices, is often suggested as an aid to aircraft punctuality. The question therefore arises as to where those items should be located. Present practice is usually to place one somewhere within the airfield boundary.

In general aircraft do not proceed direct to the airport but are routed *via* the track mesh point. This might therefore be a better position for a D.M.E. beacon—particularly if it can be adapted to give the information which is wanted from it, not only to aircraft approaching it, but also to those departing from it. Unfortunately there are four track mesh points on a two axis airfield but not more than two beacons would ever be in operation simultaneously.

While this siting is arguable, it should be noted that, in the early phases of the

approach, the destination is the track mesh point rather than the centre of the airfield. The navigation system should have due regard for this requirement.

7.5. Lateral Spacing Equipment for the Straight Approach

There are many devices which might be used as the electronic aid for parallel approaches but a ready made one may be available in the Australian Multi Track Range. Since this paper was drafted, Bowen[24] has reported that the spacing between the ground stations has been reduced to approximately two miles so that in general they can be accommodated within the airport boundaries. He also states that the accuracy with which final approach can be carried out is now of the order of plus or minus 20 yards.

While this is most promising it would be better if much of the existing equipment—G.C.A., I.L.S., Decca and perhaps GEE—could be adapted to provide tracking facilities of high accuracy over the last fifteen or so miles of the approach. It would be interesting to know the minimum lane separation using these equipments — modified if necessary—and the possibility of reducing this if some degree of altitude separation is used to accommodate the initial "turn on" errors.

8. Conclusions and Final Remarks

8.1. General

All the experimental and operational data necessary to derive indisputable conclusions do not appear to exist. As an R.A.F. officer, however, the author has always been encouraged to indicate the "best course of action" suggested by the available information and any intuition that devolves from his experience. The "conclusions" which follow are to some extent inferences of this type rather than scientific deductions. To them are added some purely personal thoughts on development organisation.

8.2. The Requirement

It is necessary to seek a system which will cater for a flow of aircraft coming from different directions and from different heights; furthermore the system should allow for the fact that there will be differ-

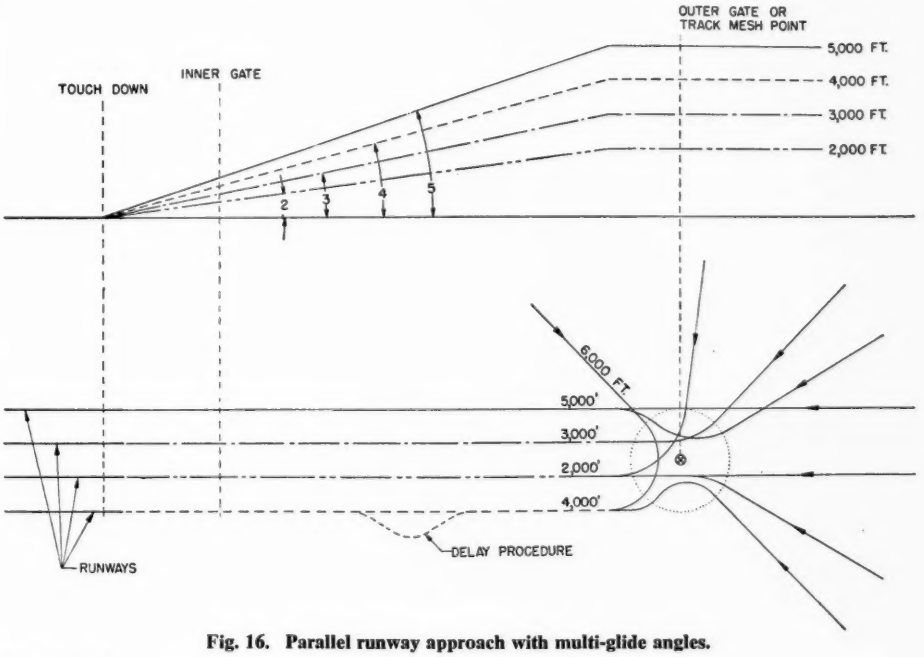


Fig. 16. Parallel runway approach with multi-glide angles.

ences between the aircraft themselves as regards the range of their practicable approach speeds. To cater for random distribution of arrival times at the outer limits, the capacity of the system must be considerably higher than the mean arrival rate in the peak hour.

For these reasons a theoretical acceptance capacity of 120 per hour—perhaps more—is a desirable target. Use of runways for take off purposes and gaps/irregularities in the flow will reduce the actual landing rate well below this.

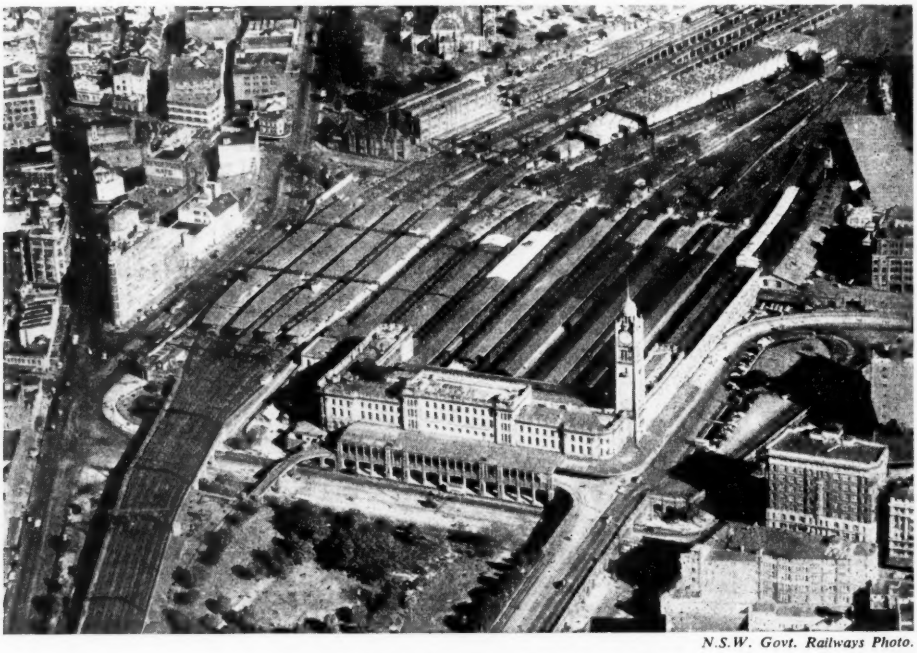
8.3. The broad possibilities

Under the rigorous conditions postulated, the maximum *sustained* flow on to one runway is not likely to exceed one per minute by 1956. Attainment of this rate will not be easy and any substantial advance beyond it seems unlikely for many years owing to the crash avoidance or "wave off" problem and other difficulties. To achieve even one per minute without stacking a high proportion of aircraft—and stacking means a delay in itself—will involve provision of new devices which are not yet fully developed. Other methods of increasing the flow must be adopted therefore to supplement longitudinal spacing.

It does seem possible to multiply the acceptance rate by provision of parallel runways coupled with the adoption of lateral spacing in the critical area between the track mesh point (zone) and the airfield. In this area the guidance problem does not appear unduly difficult.

The adoption of parallel runways—spaced perhaps a thousand yards apart—brings many bonuses but also introduces certain complications principally on the ground. These complications are considerably eased if two axis airfields can be adopted instead of the present three-axis system. The examination of this possibility is therefore a matter for aircraft and airfield designers as well as for electronic engineers. This is further discussed below.

Vertical separation at the track mesh point (zone) followed perhaps by variable glide slopes to the runway would be useful as a palliative to initial mal-spacing (lateral or longitudinal) at this focal point. It may also facilitate mixing of fast and slow aircraft.



N.S.W. Govt. Railways Photo.

Fig. 17. Parallel approach facilities—rail.

Aerofilms Ltd.

Fig. 18. Parallel reception facilities—Marine.

8 4. Longitudinal spacing in a single stream and meshing

Most promise attaches to the development of devices based on the measurement of "distance-to-go" and ground speeds. Once these data are available, it is possible to provide some form of progress comparator unit, *i.e.* a continuous "go fast, go slow" indication based on current information. Two difficulties remain to be overcome. First it is not always possible to fly an aircraft so that its ground speed is constant. Secondly it may not be possible to stabilise forward speed at the figure desired as quickly as one would like. Nevertheless this type of approach in which the actual approach ground speed is made to conform to planned ground speed or speeds offers the greatest promise. Such a device would facilitate correct meshing at the track mesh point and contribute to correct linear spacing throughout the subsequent straight approach.

Even with parallel runways and simultaneous approaches the last mentioned device would be invaluable to introduce some regularity into arrival times at the track mesh point. The degree of regularity possible is strictly limited however by inability to maintain spacing or schedule accurately during the *turn* which precedes arrival at this point. For "go fast, go slow" indication in non-linear flight, little other than surveillance radar (or adaptations of it) appears to be in sight.

8.5. Lateral spacing

Lateral spacing has been examined only in relation to the common straight track from the track mesh point to the airfield. As a system it implies provision of parallel approach lanes and parallel runways. The big query is how far apart must these lanes be placed. In view of certain practical results, it is concluded that a high standard of tracking accuracy has already been demonstrated in the air even without rate instruments. The arrival of steering indicators utilising some rate information (*e.g.* the

U.S.A.F. ID249, the Sperry Zero Reader) suggests that even better tracking accuracies are feasible.

If this accurate tracking performance can be reproduced along the common straight track preceding touch-down—that is, over the last fifteen miles (say)—it may well be possible, given suitable guidance equipment in 1955-1965, to confine 90 per cent. of aircraft on any one track to departures of less than 500 yards. This figure excludes initial oscillations following the "turn on" which could perhaps be accommodated by some measure of altitude separation between adjacent lanes at that point. This suggests a runway spacing of 1,000 yards or less. Practical trials are however necessary to establish the operational implications and possibilities with both existing devices (G.C.A., etc.) and with track guides of other types specially designed for the purpose.

Such a scheme has many attractions. Tracking errors, unlike longitudinal positioning errors, have no tendency to accumulate. The movement programmes for individual aircraft are easily defined and there is a useful contribution to the identification problem. The grouping or segregation of fast and slow aircraft is facilitated. Longitudinal bunching of aircraft in one lane can often be alleviated by inter-lane transfers. The problem of the single runway blocked by a burst tyre or crash is greatly reduced. The provision of parallel strips facilitates runway maintenance and the transition from one approach aid to new ones. By offering the possibility of landing on all runways to aircraft which track precisely and proffering only the outside, more widely separated runways to less precise aircraft, an incentive is provided to encourage the aircraft operators and pilots to improve their tracking equipment and their performance.

Against these advantages of multi-parallel runways, there must be weighed the cost of the additional paving. Improvement of aircraft cross wind characteristics to permit adoption of two axis airfields may be warranted. There are also the problems in connection with airfield surface traffic and terminal reception facilities. With a two axis airfield these are not insoluble.

Analogy is a dangerous form of argument but attention is invited to the use of parallel reception facilities in transport terminals of other types. Fig. 17 shows a fairly modern rail terminal with some twenty-three parallel tracks and twelve island platforms. Fig. 18 is a portion of the New York docks which have some hundred parallel piers.

8.6. Development Organisation and Programme Direction

In view of the stress that has been placed on the urgent necessity for a solution to this problem, there seems to be a case for the establishment of a development and evaluation organisation to make an energetic practical attack on the *overall* problem. The word "overall" is italicised because the agency required is not just an electronic development unit but one which can have due regard to other aviation factors which may require examination, *e.g.* airfield design, aircraft cross wind characteristics, aircraft speed control, chronometers and time synchronisation facilities, meteorology. The staff in some of these fields will certainly have a contribution to make to the long term solution.

In the United States in the past two years the author has met a large body of informed and influential American opinion that is keen to find, with the British, a joint solution. The resources of the two countries, properly applied, can surely achieve this. And it is most important that it be done together, or that mutually compatible solutions are chosen.

The essential pre-requisites to agreement on a single standard system are surely concurrence as to:

(*a*) Exactly what the system has to do, *i.e.* as to functional requirements. So long as development firms in U.S.A., and U.K., are given different specifications, they will inevitably produce different equipments. Nor is this just a matter of specifications.

(*b*) The performance of any equipments or systems which may be proffered as a solution. Agreement on this is not likely to arise from attendance at sales demonstrations or from uni-lateral testing.

The first of these pre-requisites suggests some form of Joint U.S.-U.K. Requirements Board or similar close consultative machinery. The second suggests Joint U.S.-U.K. Evaluations. Individual evaluations, apart from being too slow and expensive, are prone to lead to controversy about test methods and equipment.

It is therefore suggested that this civil and military problem—which is not only limiting terminal operations but costing so much in aviation fuel and payloads—be re-examined to ensure that the development plans are adequate and that they are co-ordinated wherever possible with those of U.S.A.

Finally, the author believes that if a solution is found it will make greater use of the principle of lateral spacing than is suggested by the layout of some of the terminals now in the planning and construction stages on both sides of the Atlantic.

9. ACKNOWLEDGMENTS

The author is indebted to Headquarters, United States Air Force for permission to publish certain material in this review, and to many other agencies and individuals, British and American, for assistance and advice regarding its content and arrangement.

REFERENCES

1. BOWEN, E. G. and PIERCEY, T. (1948). Delays in the Flow of Air Traffic. *Journal of the Royal Aeronautical Society*, April 1948.
2. Radio Technical Commission for Aeronautics (Washington) Special Committees 41 and 52 (SC41 and SC52) (1949). Operational and Technical Characteristics of a Transition Period Air Traffic Control Communication System; Part II, Appendix III.
3. Ministry of Civil Aviation, U.K. (1949). Pamphlet MCAP 56.
4. Air Ministry, U.K. (1950). Air Ministry Order No. A289/50.
5. Research Branch R.A.F. Transport Command (1950). Flight tests of an Off-Schedule Speed Computer; paragraphs 35-40.
6. Reference document; has a military security classification.
7. Reference document; has a military security classification.
8. Research Branch R.A.F. Transport Command. Report No. 52 (classified as "Confidential").
9. These studies by the U.S.A.F. All Weather Flying Division have not as yet been the subject of a published report.
10. DOWNES, J. G. (1950). An Aircraft Approach Procedure. *Journ. Inst. of Navigation*, U.K., Jan. 1950.
11. LUSH, K. J. (1950). Note on the Time Required to Make Level Speed Measurements with a Turbine Jet Aircraft. *Journal of the Royal Aeronautical Society*, Oct. 1950.
12. CUMMINGS, K. C. and BULLEYMONT, K. J. (1951). The Automatic Flight Schedule Controller. *Proceedings Inst. Radio Engineers' Convention*, Dayton, Ohio, U.S.A., 1951.
13. MERER, J. W. F. (1950). The Berlin Air Lift. *Journal of the Royal Aeronautical Society*, Aug. 1950.
14. COULSON, R. B. and BURGMANN, V. D. (1951). An Investigation into Air Traffic Control by a Simulation Method. *Journ. Inst. of Navigation*, U.K., Jan. 1951.
15. LYMAN, J. and LITCHFORD, G. B. (1950). The Effect of Position Determination on Air Traffic Control. *Supplement to Journ. Inst. of Navigation*, U.S.A., Dec. 1950.
16. Ministry of Civil Aviation, U.K. (1946). London Airport, Report of Layout Panel, H.M.S.O. M.C.A.P. 4.
17. Transport Command Development Unit, R.A.F. (1946). Final Report on Australian Multi-track Radar Range.
18. British European Airways (1948). Report on Initial Flight Tests with Gee Mark III, Report No. 5—Accuracy. Ministry of Supply, London, Oct. 1948.
19. Summary Report on Evaluation of Omni-Bearing-Distance System of Air Navigation (1950). W. R. Rambo, J. S. Prichard, D. P. Duffy and R. C. Wheeler. Report No. 540-1. Airborne Instruments Laboratory, Mineola, New York, U.S.A., Oct. 1950.
20. WILLIAMS, CARADOC (1948). Fundamental Considerations affecting Air Traffic Control Methods. Royal Aircraft Establishment, Farnborough, Tech. Note No. RAD 421.
21. AYERS, R. H. (1949). The Aerodrome Problem Related to Aircraft Design and Operation. *Journal of the Royal Aeronautical Society*, Sept. 1949.
22. HART, C. A. (1950). Air Survey. *Journal of the Royal Aeronautical Society*, Oct. 1950.
23. AIKEN, W. S. (1946). Tables and Charts for Use in Calculation of Airspeeds. N.A.C.A. Technical Note No. 1120.
24. BOWEN, E. G. (1951). The Navigational Work of the C.S.I.R.O., Australia. *Journ. Inst. of Navigation*, U.K., Oct. 1951.
25. The Airport and its Neighbors (1952). Report of the President's Airport Commission. U.S. Government Printing Office, May 1952.

APPENDIX

WEATHER CONDITIONS AT SELFRIDGE AIR FORCE BASE

29th April 1951, 15.00 hr. Z.

Height: ft.	*Air temperature: °C.*	*Wind direction (degrees) and Speed (knots)*
0	19	180/6
1,000	13	200/6
2,000	12.5	250/10
3,000	12	250/12
4,000	10	280/11
5,000	9	290/15
6,000	8	300/23
7,000	5.5	300/28
8,000	3.5	290/34
9,000	3.5	270/34
10,000	2	260/40
11,000	−1	——
12,000	−3.5	250/50
13,000	−5	——
14,000	−7	250/46
15,000	−9	——
16,000	−12	260/52
17,000	−13	——
18,000	−15	260/47
19,000	−16.5	——
20,000	−19	260/59
21,000	−20	——
22,000	−22	——
23,000	−24	——
24,000	−28	——
25,000	−31	280/50
26,000	−34	——
27,000	−36	——
28,000	−38	——
29,000	−40	——
30,000	−42	*300/45
31,000	−44	——
32,000	−47	——
33,000	−49	——
34,000	−51	——
35,000	−54	*300/40

NOTES—1. Figures by courtesy U.S.A.F. Weather Staff, Wright-Patterson Air Force Base, U.S.A.

2. Intermediate winds were interpolated.

3. Winds marked with an asterisk were estimated from upper level pressure charts.

DISCUSSION

D. O. Fraser (Ministry of Civil Aviation, *Associate*): He was a little puzzled about what was achieved by scheduling *en route*. Group Captain Whiteley visualised that it would be possible to schedule *en route* so that aircraft would arrive at the entry point to the final approach within half a minute of schedule. That seemed a terrific achievement, particularly because civil aviation dealt with approaches from different directions, and a change of wind speed would affect aircraft approaching from opposite directions in the opposite way. It seemed doubtful whether such close scheduling would be practicable for civil operations, even assuming appropriate aids to navigation were available.

Even if such close scheduling were possible, there remained the problem of bringing the aircraft over the runway threshold at exactly even intervals. Up to this point the vertical holding stack achieved what the proposed route organisation and schedule-keeping endeavoured to do; it delivered aircraft at the bottom of the stack at intervals with an accuracy of $\pm$ 1 minute, which might be improved in the future. He did not think that a sufficiently strong case had been made against the stack as a means of de-randomising arrivals.

The table showing attainable tracking accuracy with various aids was extremely interesting. He had not previously seen the figures brought together. It looked as though eventually tracking systems might be relied on to segregate aircraft so that they could be controlled independently while landing on separate runways. He did not think full advantage could be taken of parallel runways at large airports until this could be done. From the table it appeared that, even with the present separation between the dual parallel runways at London Airport, it might be possible in the near future to have aircraft approaching and landing independently.

Group Captain Whiteley: His purpose was to emphasise the possibilities of, and necessity for, parallel approaches rather than to advocate any particular system of fine longitudinal spacing. However it was desirable for economic reasons to exploit each runway to the maximum and for this purpose he had suggested allotting E.T.A.s *at the track mesh point*—not elaborate *en route* scheduling. He had discussed one per minute sequencing (and, for this, timing to within half a minute would be required) but his final conclusions at the end of Section 5 were that it would be extremely difficult to achieve one per minute in the general case.

He had made no attempt to point up the case against stacking. There were two general types of stacking, in the clear above the overcast and in the cloud. Every minute spent in the stack, or liable to be spent there, represented wasted fuel and loss of payload.

Stacking in the clear above the overcast was practicable when the cloud layer was relatively thin. Aircraft could space themselves visually above the cloud and descend under constant airspeed technique with radar surveillance. This had its uses with homogeneous groups of aircraft but there were serious limitations, *e.g.* if the cloud layer were turbulent and of great vertical extent mal-spacing developed during the descent.

Stacking in cloud required more supervision. With the arrival flow which he envisaged in his assumptions for 1960-5, very large stacks would arise if this were the only method of regularising the flow. The internal management of large stacks would produce a traffic problem of its own. Furthermore once an aircraft was in a stack it was difficult to bring it forward at the precise moment it was wanted because of the difficulties of making good an E.T.A. at the end of a *non-linear* descending track. Just when an aircraft was wanted to emerge from the stack it was often at the far end of its circuit, heading in the wrong direction. While the stack was useful in the present phase, these problems made it difficult to reduce the interval between successive aircraft. Fine spacing between aircraft depended on "go fast, go slow" indications in the cockpit and it seemed easier to provide this automatically if the approach tracks were predominantly straight.

To illustrate his thoughts on regularising the flow, he envisaged aircraft arriving at the outer boundary of the terminal zone with some degree of bunching. There might be, say, 15 aircraft about 150 miles away planning to arrive at the track mesh point between 10.05 and 10.10. He suggested that the early aircraft be accelerated by up to four minutes and the later ones retarded by small amounts so that the aircraft arrived evenly

spaced at 10.01, 10.02, 10.03, . . . 10.15. It might well be possible during the descent at light weight to vary the air speed and to do this without significantly increasing the total fuel consumed. To permit this adjustment he had suggested an E.T.A. indicator or an equivalent "go fast, go slow" indicator.

Mr. Fraser: It seemed that in the example quoted, the overall gain would be four minutes less delay, because an aircraft due at 10.05 hours would arrive at 10.01, and others would follow accordingly. There was a gain only in so far as a gap had been filled, by using the runway at a time when it would not have been in use if the aircraft had been left to arrive at random. Beyond this there was no gain in time for subsequent aircraft, whether they were delayed by adjusting speed as proposed or by holding in a stack. De-randomising was being proposed *en route*. It could equally well be done between the bottom of the stack, or gate, and touch-down, so attaining the same landing intervals.

Group Captain Whiteley: He agreed that this would be so *provided that* the same fine spacing could be achieved between the bottom of the stack and touch-down. A certain amount of time and distance was necessary. He doubted whether fine landing intervals—say 80 seconds with mixed aircraft—could be sustained without new types of equipment such as he had suggested, *e.g.* an E.T.A. indicator. Any aircraft fitted with such a device would use it not only to regulate his time at touch-down but also to adjust his arrival time at the track mesh point; the latter procedure would make it unnecessary (normally) to enter the stack.

A. E. Slocombe (British European Airways, *Associate*): Unless a constant approach speed could be assumed there might be inadequate separation between two aircraft between 'touch-down' and the track mesh point. Approaches, therefore, would only be safe if the aircraft were on adequately spaced paths to parallel runways.

Was the lecturer suggesting a constant approach speed for all aircraft?

Group Captain Whiteley: He agreed that it was not practicable to do this. The problem of mixing fast and slow aircraft was illustrated by Fig. 4. Briefly his suggestion was to use parallel runways and make each stream as homogeneous as possible; in conjunction with this, departure times at the track mesh point would be adjusted for fast and slow aircraft to ensure correct spacing at touch-down. To permit such a system he had suggested some height separation at the track mesh point between successive aircraft.

I. F. B. Walters (Ministry of Civil Aviation): The maximum glide slope used in the United Kingdom at present was about $4\frac{1}{4}°$, and that could be used only in a wind of between 20 and 30 knots down the runway, so that the effective rate of descent of the aircraft was as if the glide slope was $3\frac{1}{2}°$. Using the glide slopes as a measure of vertical separation would involve high figures, and he imagined that glide slopes of 20°, 25° or 30° would be needed.

Even to do it in a small way would mean, at least, doubling the existing glide slope. But there was no existing civil aircraft which would cope with more than $3\frac{1}{2}$-4° and, so far as he could see, there would not be a civil aircraft which could double that before about 1970. He might be wrong, but he felt that to expect it this side of 1965, at any rate, would be extremely optimistic.

To use the runways to the capacity that Group Captain Whiteley would like, the actual time during which the aircraft were on the runway must be reduced to a minimum. So that, on the configuration which the author had shown, there would have to be a series of strategically placed turn-off points, in herring-bone pattern.

Group Captain Whiteley: He agreed that provision of a large number of strategically placed "turn-offs" was essential. They had been omitted deliberately from his diagrams for purposes of simplicity.

As to variable glide slopes, he had not envisaged angles of 20 or 30°. A difference in glide slope of one degree would constitute a difference in height of about 1,300 ft. at a distance of 15 miles from touch-down—and that was about the range he had suggested for the track mesh point. It followed that a spread of glide angles from about 2-5° would provide considerable altitude dispersion. The U.S.A.F. glide slope transmitter AN/MRN8 could be set up roughly over this range.

His intent had been primarily to indicate the value of height separation at the track mesh point, as a palliative to other troubles there. The provision of multiple glide slopes

facilitated this but the technique could still be adopted with only a single glide slope. Aircraft approaching at different levels would intercept it at different distances from touchdown.

E. S. Willey (British Overseas Airways, *Associate*): He had gained the impression that some of the problems of which the author had spoken arose from the use of a single airport for each population centre. Did the author feel that his problems could be decreased by the development of more than one airport per centre?

The author offered a solution for 1955 onwards, but he was rather concerned with the years between now and that time. The operators were progressively going to produce more and more aircraft for the Air Traffic Control systems, and the apparatus and organisation which the author had suggested in his paper would take a long time to develop: much of it could not be expected before 1955, and perhaps even that was optimistic. Had the author any means for the years between now and 1955, with which to solve the problems which might arise?

Group Captain Whiteley: He did not know the present acceptance rate in the United Kingdom, but he had seen a demonstration of an S.C.31 Transition System in the United States by the Air Navigation Development Board in conjunction with the Civil Aeronautics Administration. At this they had achieved a landing rate with mixed aircraft of just over two minutes over a period of about four hours.

He believed it would be difficult to maintain that figure; it meant very hard work for all concerned on the control staff, for the reasons mentioned earlier; they had to talk to each aircraft individually, directing and authorising each movement. Anything that was being done in the United Kingdom to effect improvement between now and 1955 must be part of a programme already in hand, and he was out of touch with what was going on here.

As to the use of duplicate airports at community centres, the result might be to increase the problems. In the New York area they had 1,000 arrivals per day with three airfields. They required a complex approach system and experienced very considerable delays at times.

For reasons given at the end of Section 6.8, more use could be made of four runways placed together than from two runways on each of two airports. He felt personally that the amount of equipment and personnel which could be "processed" through an air terminal could be multiplied considerably, and the facilities available at every terminal should be used more than, in fact, they were.

E. S. Fischeles (*Assoc. Fellow*): The author had referred to the acceptance of 120 aircraft per hour; that would mean 6,000 people arriving at an aerodrome every hour, which would call for tremendous effort on the part of the aerodrome staff. How would they manage about Customs formalities, and so on?

How would the aircraft be dispersed for unloading? What means, for example tube trains or motor coaches, would be used to transport passengers to and from the aerodrome? Would there be separate runways for take-off?

Group Captain Whiteley: He would not be able to discuss the question of acceptance requirements in any detail in the limited time remaining, but he had studied it carefully before suggesting the acceptance *rate* of 120 aircraft per hour; in the text of the paper there were references to studies which had been made of the problem. One of these (Ref. 2) gave figures rather higher than he had adopted.

He emphasised two things. First, the answer to avoiding delay was to increase the acceptance capacity. Whenever an airport was used at anywhere near its maximum capacity, there would be trouble. An airport must be designed with a capacity far above that at which it would normally be used (*See* Ref. 1).

Secondly, there was the question of departures, which he had not dealt with in the paper because clearing the runways of arriving aircraft automatically made more space for departures. Obviously, legislating for a lot of departures meant a higher acceptance rate, if no separate provision were being made for them.

From these two remarks it would be apparent that he was not necessarily expecting 120 aircraft to land in one hour; but following a large diversion programme they might be faced with 30 aircraft approaching in a 15-minute period, followed by others at a lesser rate.

With regard to passenger handling, congestion seemed inevitable if all aircraft, vehicles and passengers were brought to a single central terminal building. With decentralised reception, as at Southampton and New York docks, it was possible to handle very large volumes of traffic. He had obtained from the Cunard Company details of the rate at which passengers were cleared from the *Queen Elizabeth* and had come to the conclusion that the passenger reception problem should not be a limiting factor in determining airport reception capacity, provided that the original layout allowed for some measure of decentralisation.

H. M. March (Ministry of Civil Aviation, *Associate*): He had hoped to hear rather more about how the aims mentioned would be achieved; could the author say more about American ideas on the future of Air Traffic Control? In other words, with the congestion that was envisaged along the route and around the terminal area, were they thinking in the U.S.A. of a system based mainly on a ground control using radar, or would the control be placed more in the hands of the pilot, allowing him to do his scheduling along the route by means of an automatic system, with the information sent to him by radio from the ground being confined to arrival and landing instructions, with which he should try to comply?

Group Captain Whiteley: In the U.S.A. the work was going on in two directions in the field of civil aviation. There was considerable work on the development of entirely ground-based radar systems, *e.g.* by Gilfillan. The system he had illustrated by a diagram, and which endeavoured to give a "go fast, go slow" intimation, might be derived from a ground surveillance system. There was also development activity on airborne systems, rather like that which he had illustrated. Both schools of thought had their supporters.

There were others present who could say more than he could about what was happening in the United Kingdom.

K. Paton Jones (Ministry of Civil Aviation): He was particularly interested in the author's suggestion that the aircraft could be de-randomised before they reached the track mesh point; he understood the chief requirements were for an extremely accurate navigation aid over a radius of 150 miles, and what he believed would be much more difficult was to provide accurate information on wind velocity from ground level to 40,000 ft. over that area. Did the author know of developments in the navigational field which would provide the movement co-ordinator with the information required to achieve his spacing, and did he expect by 1955 a meteorological service which would provide him with information of the accuracy that would be required?

Group Captain Whiteley: He did not know what the meteorological service was doing about upper wind forecasts. In the system he had suggested there was not much requirement for precise information on wind speeds, except to decide upon a reasonable E.T.A. at the track mesh point. He would try to allot to each aircraft an E.T.A. at the track mesh point. The pilot should then be provided with "go fast, go slow" instructions, not based on estimated wind velocities, but based on the actual measurement of the distance to go and his actual ground speed. In other words, he wanted to make it as far as possible independent of forecast winds. To ensure that the E.T.A. allotted was practicable, it would be necessary to have a forecast of the wind structure over the last 200 miles but there should be sufficient speed flexibility during the descent to allow the E.T.A. to be achieved, even if there were minor inaccuracies in the wind forecast on which it had been selected.

Postscript:—

By courtesy of the Chairman (Lieut.-General James H. Doolittle) he had recently received a copy of the Report[25] of the President's Airport Commission completed in the United States in May, 1952. He was interested to note that the recommendations of this body included the following:—

Recommendation 15. "New airports should adopt a single or parallel runway design. This should be adequate except under strong wind conditions, in which case a shorter runway at 90° to the main one may be required. Airport expansion should be achieved through additional parallel runways."

Recommendation 13. "Existing cross-wind component limitations should be reviewed to establish more liberal cross-wind landing and take-off specifications for each transport-type aircraft."

*Some Notes on Aircraft Overhaul and Maintenance**

by

CLIFFORD H. JACKSON, B.Sc.(Eng.), A.F.R.Ae.S.

1. Introduction

Commercial aircraft, in common with all public transport, must be subjected to routine inspections and regularly overhauled in the interest of both safety and economy.

Aircraft maintenance and overhaul are not just the domestic concern of the organisation doing the work. There must be adherence to Standards approved by the Air Registration Board on behalf of the Ministry of Civil Aviation; and these Standards are the national interpretation of some of the directives issued by the International Civil Aviation Organisation as part of the international agreements regulating air safety. The regulations are neither rigid nor detailed, but they exist for the protection of air travellers against the remote chance of an operator failing to maintain airworthiness. In particular, they call for regular maintenance checks and, to procure annual reissue of the Certificate of Airworthiness, an annual overhaul or its equivalent.

Maintenance and overhaul are not just matters of mechanical reliability; the International Civil Aviation Organisation sets Minimum Performance Standards for certification of airworthiness and the required rates of climb, ground clearances, and aircraft manoeuvrability must be maintained on commercial operations. This means that authorities such as the A.R.B. have responsibility for checking maintenance even to the extent of calling for periodic flight tests and for weight adjustments if the aircraft or engine datum performance cannot be assured.

The safety and economic aspects of overhaul and maintenance are superimposed on the commercial aim, which is simply the cheapest production of the goods sold, namely seat-miles or ton-miles. The problem is to make the engineering side of production operate as smoothly and economically as that of any factory, even though the engineering tends to be more experimental than straight-run production.

A partial answer is superimposing Progressive Overhaul on the Planned Maintenance Inspections. This is the subject of these notes—but only in relation to airframes.

The overhaul of power plants and major accessories is not discussed except incidentally, even though it represents the larger portion of maintenance and overhaul expenditure. However, only a small proportion of the subject can be covered in this paper, which must be confined to the one aspect, airframe maintenance and overhaul. There is now a well established background and basis for this work; in fact, in terms of man-hours and material per capacity-ton-mile offered for sale, there is little to choose between the techniques of the various operating Lines, even though they vary in some respects according to local preference and type of aircraft. The same conclusions would probably result from a comparison of the economics of different operators, thus showing that the next important move in a drive towards better engineering economy will be centred on component overhaul procedures. This is outside the scope of the present paper.

It is of interest to note some of the aircraft of the past, on which much of the technique

*These notes were first prepared for a talk to the 1950 Technical Conference of the International Air Transport Association. They were subsequently used for lectures to the Weybridge and Bristol branches of the Royal Aeronautical Society on 18th October 1950 and 17th February 1951.

Because the paper was written approximately two years ago it is not necessarily in accordance with present-day procedures in certain details (for example, B.O.A.C.'s fleet of aircraft has been increased), but the particular issues reviewed still exist and in essentials, such as the bases mentioned, the position is the same.

Some of the opinions expressed are those of the author and do not necessarily represent those of the Corporation.

Mr. Jackson is Manager, Operations Development Unit, British Overseas Airways Corporation.

has been built up within the memory and experience of most of those now in air transport. To some extent these represent a complete epoch of short- to medium-range aircraft. The wartime advent of long-range, high-speed aircraft, such as the Liberator, and "converted" Lancaster, introduced a new era in air transport and had a marked effect on overhaul and maintenance procedures, preparing us, first, for the current long-range aircraft and, now, for the latest products of the British Aircraft Industry.

2. B.O.A.C. BASES

It might be said that the bulk of our revenue, and some of our engineering servicing, is developed overseas, but the bulk of our production engineering must be at home in the United Kingdom.

In speaking of B.O.A.C., it must be remembered that there are still problems of bases and equipment which derive from post-war supplies and building difficulties, but which will be resolved as London Airport and its workshops and hangars are completed. At present, engineering policies and standards are set up with establishments distributed as follows:—

No. 1 Line, consisting of 22 Argonaut aircraft, operated from and overhauled and maintained at London Airport, and serving South America and the Far East.

No. 2 Line, consisting of Hermes aircraft for operations to East, South and West Africa, and based at London Airport.

No. 3 Line, based at Filton, about 120 miles from London, and consisting of firstly, 5 Constellation 749 aircraft operating between the United Kingdom and Australia; secondly, 5 Constellation 049 aircraft serving the Caribbean area via the Middle Atlantic route; and thirdly, 10 Boeing Stratocruisers operating between the United Kingdom, Canada and New York.

Maintenance of this fleet is divided between Filton and London Airport, but all overhaul is being carried out at Filton.

It is only comparatively recently that the Hermes fleet was transferred to London from Hurn, some 90 miles away; the Solent flying boat operations, from Southampton and Hythe, ceased at about the same time because of the full introduction of the Hermes.

Until about a year ago, some Avro York aircraft were based at Kingston, Jamaica, to serve the West Coast of South America; but the York fleet, 10 aircraft, has now been consolidated and based at London Airport*.

With the earlier distribution of bases and aircraft types, there was some variation, probably advantageous for development, between bases on the detail engineering procedures; but the staff policy, inspection standards and basic principles are uniform and set by Head Office; the supplies and purchasing organisation, of course, are centralised.

The position is now simplified, though not yet to the desired extent, and the examples in this paper, *i.e.* the Argonauts based at London Airport, and the Constellations and Boeings based at Filton, are fairly representative. (The Hermes was not in full operation as a fleet when these notes were first presented as a lecture, and the full overhaul procedures, generally similar to those for the other aircraft, had not been practised up to full Check 4 standard, simply because the appropriate number of flying hours on any one Hermes had not been accumulated at that date.)

3. PROGRESSIVE OVERHAUL

The overhaul and maintenance procedures of B.O.A.C. and its predecessors have progressed from routine maintenance inspections with an Annual Overhaul, through Progressive Overhaul by calendar dates, up to Progressive Overhaul combined with maintenance inspection, on an aircraft-flying-hours basis.

This development of Progressive Overhaul by B.O.A.C., and most other major airlines, has been so important, yet so unpublicised a feature of the air transport industry, that it is worth pointing out some of the essential features, elementary though they may seem.

3.1. OBJECTIVES

Assuming the over-riding requirements of airworthiness, the primary objectives of Progressive Overhaul, as distinct from Annual Overhaul, are straightforward production matters, such as:—

(*a*) Maximum aircraft utilisation within the limits of the required commercial schedules and aircraft performance.

(*b*) Best maintenance and overhaul economy by ensuring a continual, and not spasmodic, flow of work to the hangars and workshops and hence

*The Yorks are now operating a freighter service to Singapore.—Ed.

(*i*) Minimum idle time for staff and workshop equipment.
(*ii*) Minimum idle time and days for aircraft.
(*iii*) Minimum unplanned night shift and overtime.
(*c*) The centralising of overhaul and maintenance facilities and the reduction of technical staff, equipment and spares holdings overseas.

The earlier annual C. of A. overhaul procedure, and even partial approaches to Progressive Overhaul, had the inherent disadvantage of doubt as to the time an aircraft would spend in the hangars because of minor unforseen defects, not revealed by normal maintenance, which could develop during a six or twelve month calendar period. The combination of Progressive Overhaul and Maintenance Inspection eliminates this doubt and allows engineering and operational planning to be based on aircraft entering the hangars for defined periods, less than that required for the older conception of an Annual Overhaul, at specific hourly intervals in an agreed total of flying hours.

The present foundation of Progressive Overhaul is the establishment and approval of component overhaul life in hours. In general, component lives are established and improved only by experience and inspection, supported by analysis of spares requirements. In some cases, research work by the operator improves a component life; generally, sources of heavy expenditure are revealed by returns of consumable spares, reports from the Lines of inconvenience and delays, and B.O.A.C.'s Technical Investigation Report procedures, and these lead to discussions with, and subsequently action by, the component manufacturers.

As technique develops there is a tendency to depart from the conception of component lives fixed in terms of flying hours and to substitute, where possible, overhaul only when inspection proves the necessity. This approach, requiring close co-operation with the airworthiness authorities, is promising economies in component overhaul costs, which may offset the inconveniences it would introduce into inspection procedures, supplies scheduling and overhaul planning.

3.2. Overhaul Work and Maintenance Routines

As with most operators, a servicing and maintenance inspection system using about four main checks is used.

For example, with the Argonauts, the checks carried out are:—

Check A: Refuelling and Departure Check.
Check 1: Maintenance at approximately 50 hours.
Check 2: Maintenance at 100 hours and requiring about 300 man-hours and 50 elapsed hours.
Check 3: Maintenance at 200 hours and requiring about 700 man-hours and 90 elapsed hours.
Check 4: Maintenance at 600 hours and requiring about 1,300 man-hours and with overhaul, as mentioned later, about 5/6 days elapsed time.

There is no point in quoting full details of each maintenance check. In general, their characteristics are as follows:—

Check 1 consists mainly of servicing all levels and pressures; servicing the passenger chairs; external inspection for leaks and routine cleaning of filters; functioning checks on the essential services such as blind flying instruments, radio and so on. Check 2 is a somewhat extended version of Check 1. Both are preferably completed at the home base or terminal destination, but with only 50 hours between Checks 1 and 2 this is not always possible. Either could, and often is, completed in the open by what might be termed a "Tarmac Team," and both are quite distinct from the later Checks 3 and 4 for which proper hangar facilities are essential.

Check 3 is the stage at which replacements of some time-expired components may occur, inspection panels are removed for inspection of control runs and hinges; heater units are checked; wheels, brakes and hubs are examined; hydraulic system components are checked; water tanks are removed and sterilised and so on. In fact, at this stage, there may be 170 listed airframe items and a further 50 or 60 items for each power plant.

The Check 4 introduces numbers of overhaul items in the list of time-expired components; there is a greater stripping down of internal and external panels and floor boards, for inspection of structure, details of fuel systems, control runs, hinge attachments and so on. The electrical system and instrument installation receive most detail inspection, and functioning checks and corresponding work are made on the power plants if they are not time-expired.

1	Power Plants and Propellers: checked externally for leaks and general condition	1..... 2..... 3..... 4.....
2	Oil Pressure Filters: inspected, cleaned and refitted *..... *(This item to be carried out only where specially called for on Schedule of Routines.)	1..... 2..... 3.....
1	Aircraft checked externally for damage	.....
2	Main and Nose Wheels: visual check for condition and creep	.....
3	Main Wheel Tyre Pressures checked (90 P.S.I.)	.....
4	Nose Wheel Tyre Pressures checked (65 P.S.I.)	.....
5	Flying Controls and Trim Tabs: checked for freedom and range of movement (return to Normal)	.....
6	Aircraft checked internally for cleanliness and condition of furnishings and equipment	.....
7	Fuel Strainers, Tank Sumps and Cross-Feed drained	.....
1	Refuel. Petrol and Oil. Enter quantities in Tech. Log (individual petrol tanks)	.....
2	Check and top up as necessary the following: Coolant systems, Hydraulic, Oxygen, Pneumatic and Auxiliary Gear Box systems	.....
15	Pitot Head: heating checked	.....
16	Landing struts and tyres: inflation appears normal	.....
17	Fuel, Oil and Coolant filler caps checked for security	.....
18	All cowlings checked for security. All doors, hatches, emergency exits and inspection covers secure	.....
*19	Aerofoil surfaces and hinge points free from ice and snow	.....
*20	Technical Log signed and on board	.....
*21	All Loose Equipment on board and suitably stowed, and unauthorised items removed	.....
22	Check fuel drain cocks for correct position and locking	
23	Check that circuit breakers Nos. 55 to 59 are in the ON position (main base only)	

Fig. 1. Refuelling and departure check. Extract from typical Check "A."

It is at this stage, *i.e.* Check 4, that airframe maintenance inspection merges into overhaul and it becomes economic to introduce structural and component overhaul in some of the areas under routine inspection. The aircraft are therefore never taken off service for an annual overhaul. Instead a portion of the overhaul is superimposed on the Check 4 inspection routine; this probably doubles the elapsed time which would otherwise be required for the inspection routine, but the total elapsed time is still only about five days.

The foregoing illustrates the difference between the Checks 1 and 2, and the later Checks 3 and 4. The complexity of the tasks differ and there are distinctly different approaches to the job. With Checks 1 and 2, it is that of a team operating to an urgent plan to complete work on a service aircraft within a matter of hours. With Checks 3 and 4, the team is working on a more complex programme, involving much dismantling; the aircraft is actually off service for a limited period and the full facilities of hangar and overhaul workshop are called into action. Figs. 1 to 4 show extracts from typical inspection lists and may help to clarify the conception of the system.

The Argonaut planning is based on 2,400 hours annual utilisation per aircraft and the completion of overhaul during eight Checks 4 at 600-hour intervals. (These Check 4 periods have been extended since this paper was presented.) The overhaul is therefore spread over an estimated two-year period; this period, fixed by the utilisation and component life, has been approved by the Airworthiness Authorities, who also approve details such as the specific hourly overhaul lives for the various components.

It is recognised that some aircraft, because of the nature of their operational use (for example, diversion to low utilisation

Item		*Mech.*	*C/Hand*	*Insp.*
A. 1	Captain's Report: Transfer to Inspection Sheets for action	—	—	
	Control Cabin			
AA. 1	Flying Controls and Trim Tabs, including indicators and gust locks; operation and full range of movement checked	—	—	
AA. 2	Furnishings, Windows, Equipment and Clear Vision Devices: checked for condition, security and cleanliness			
AA. 3	All Safety and Emergency Equipment: checked for serviceability security and full complement	—	—	
AA. 4	Brake Pressure System: apply parking brake and ensure pressure is maintained	—	—	
AB. 6	Brake Emergency: air bottle pressure checked (1250 P.S.I.). Corrected as found necessary		—	
AB. 7	Hydraulic Reservoir: fluid level checked. Replenished as required		—	
AB. 8	Hydraulic Accumulators: pressure checked NOTE.—Air pressure—system uncharged—1000 P.S.I.) (System fully charged hyd. pressure is 3000 P.S.I.)	—	—	
AB. 9	Brake Accumulator: Air pressure checked (1000 P.S.I.) static	—	—	
	Mainplanes			
AC. 1	Mainplanes, including all Control Surfaces and Trim Tabs: general condition and cleanliness checked			
AC. 2	Fuel Tanks: examined externally for leaks	—	—	
AC. 3	Fuel Line Strainers: examined and refitted			
AC. 4	Fuel Drain Cocks: checked for water and relocked		—	
	Landing Gear			
AD. 1	Main Wheel Assemblies: condition checked L Tyre pressures checked (90 P.S.I.) checked for creep R	— —	— —	
AD. 2	Nose Wheel Assembly: condition checked. Tyre pressure checked (65 P.S.I.) checked for creep	—	—	
AD. 3	Main and Nose Landing Gear Structures: condition and cleanliness checked, including shock struts and micro switch gear			
	Empennage			
AE. 1	Tailplanes, Fin, Control Surfaces and Trim Tabs: general condition and cleanliness checked			

NOTE.—All adjustments of controls require duplicate inspection

Fig. 2. Aircraft maintenance routine. Extracts from a typical Airframe Check I at 50 hrs.

programmes on training, special survey flights) might not, in two years, complete the hours to justify eight Checks 4. Discussions have taken place with the A.R.B. as to the possibility of waiving the two-year limit in such instances, and accepting the completion of all overhaul work within a given number of operating hours which would be somewhere, as convenient, between 4,800 hours (the time for eight Checks 4) and, say, 6,000 hours (which might be the maximum life between overhauls which the A.R.B. will grant for an appreciable portion of the structure and fixed components of systems).

There is a case against such concessions; training and local flying can impose arduous loading on an aircraft and, equally, nothing can lead so effectively to airframe and system deterioration as a period of low utilisation, but, in general, the procedures have been justified and no difficulties have been experienced.

With a fleet of 22 aircraft, the procedures discussed give the following allocations:—

2 aircraft on training;
2 aircraft undergoing modification;
18 aircraft on the service roster.

As the operations and fleet utilisation build up to the ultimate plan, the number of aircraft on the service roster will probably increase to 20. Of the present 18, the hangar shops will always reckon on having, over a given short period,

4 aircraft on Check 3;

2 aircraft on Check 4 plus overhaul; this is the normal figure of one fifth to one quarter of the operation fleet.

B.O.A.C.'s No. 3 Line, with the divided engineering work, carries out Checks 1, 2 and 3 on the Constellations at London Airport, with Check 4 plus some overhaul at Filton. For the Boeings, Checks 1 and 2 only are at London Airport with Check 3 at Filton until more experience has been gained and until the initial modification programme normal with a new type has been largely completed. Checks 4, when they become due, will be made at Filton and, as with the Canadair and Constellation, an overhaul sequence will be carried out during the Check 4.

With aircraft based at Filton, the programme calls for, and hangar and workshop capacity permit,

2 Constellations on Check 4 plus overhaul;
1 Stratocruiser on Check 3;

Item		*Mech.*	*C/Hand*	*Insp.*
A. 1	Captain's Report: transfer to routine sheets for action	—	—	
	Control Cabin			
AA. 1	Remove panels Nos. 285, 298, 295, 302 to facilitate inspection of flying controls		—	—
AA. 2	Flying controls and trim tabs, including indicators and gust locks: operation and full range of movement checked	—	—	
AA. 3	All trim tabs: mechanism and controls checked for condition and cleanliness	—	—	
AA.10	Air ducts and regulators: condition and operation checked		—	
AA.11	Hydraulic system: check all units for condition and leaks		—	
AA.12	Entrance door: check seal for deterioration, latches and hinges, for condition and operation		—	
AA.13	Windows: inspect condition, security and cleanliness	—	—	
AA.14	Windscreen: remove inner glass, clean, check condition and re-fit		—	
	Fuselage			
AB. 1	Remove panels Nos. 265, 270 and 309 to facilitate inspection of flying controls		—	—
AB. 3	Elevator and trim tab controls, fittings, pulleys and fairleads inspected	—	—	
AB.10	Drinking water tanks drained, removed, cleaned and sterilised, tanks refitted and filled all in accordance with Medical Memo. No. 28, Sect. III as amended		—	
AB.23	Cabin expansion turbine: general condition checked, oil drained and refilled			
AB.24	Heater System: general condition and security of assembly in Heater Compt. checked. Drain condensator tank		—	
AB.25	Interior of tail cone: general condition and cleanliness checked	—	—	
AB.27	Passengers' seats and lapstraps checked for condition and security	—	—	
AB.28	Passengers' lifebelts: check serviceability, full complement, date stamp and stowage	—	—	
AB. 6	Gust lock controls and mechanism, check general condition, operation and for excessive play at aileron, rudder and elevators with gust lock on	—	—	
AB. 7	Main Entrance door: check seals for deterioration, latches and hinges for condition and operation		—	
AB. 8	Cabin windows: condition and security checked	—	—	
AE. 4	Rudder, elevator and trim tabs: inspect hinges and attachment joints for condition and security checked	—	—	
AE. 5	Rudder and elevator controls: cables, fittings, pulleys and fairleads inspected	—	—	
AE. 6	Rudder and elevator trim tab controls: cables, fittings, pulleys, fairleads and operating rods inspected	—	—	
AE. 7	Refit all inspection panels			

NOTE.—All adjustments of controls require duplicate inspection.

Fig. 3. Aircraft maintenance routine. Extract from a typical Airframe Check III at 600 hrs.

1 Stratocruiser on Check 4 plus overhaul.

This gives the same division as for the Argonaut, *i.e.* about 80 per cent. of the fleet on service. A better picture of the allocation of aircraft time might be given by saying that, in very rough figures, each aircraft spends, out of every 24 hours, 8 hours under maintenance, 8 hours on service (about 5 of which are flying and 3 standing at transit stations for traffic and operational reasons); and 8 hours on the ground at terminal base or overseas because of schedule or operational limitations. Naturally, as utilisations increase, some of the last mentioned 8 hours will be absorbed.

3.3. Examples of Airframe Sub-division for Overhaul

It is worthwhile illustrating the divisions of the overhaul work on, for example, the Constellation 049 and the Argonaut.

The Constellation 049 overhaul programme is broken down into 23 main headings, which are covered, about six items at a time, during six Checks 4, as shown in Fig. 5. Fig. 6 shows the Argonaut overhaul programme, which is broken down into 31 items and completed during a total of eight overhauls spread over 4,800 flying hours.

The fleet programme for all six overhauls on the Constellation is planned in advance. The items to be covered during any one

Station..... Check IV
Aircraft..... Date.....
Certificate of inspection and checks carried out in accordance with approved Schedule of Inspection for Check IV. Task cards allocated to Operatives by Chargehand.....Signature.

Certificate of Work Done				Inspector's Survey carried out as Directed.				
Card Ref.	OPERATIVE Block letters.	Sig. of Ops.	Insp. Init.	Card Ref.	Loc. No.	Location	Reference Defects Report	Inspector's Signature
A/F				FP	1	Forward		
L/H 1								
A 1				"	2	& Rear of		
2								
B 1				"	3	Fire Walls		
2								
C 1								
2								
D 1				"	4			
2								
Inst.				"	5			
A 1								
2				"	6	Fuel		
Elect.								
L/H 1				"	18	System		
A 1								
2				"	21			
B 1								
2				"	7			
C 1								
2				A/F	5-6 & 13	Landing Gear		
D 1								
2								
Radio				"	7	Cockpit		
A 1								
B 1				"	8	Flight Deck		
P/P								
L/H								
A 1				"	13-16	Fuselage		
2								
3								
B 1				"	16	Tail Section		
2								
3								
C 1				"	17-18	Port M/P		
2								
3								
D 1				"	20-21	Starbd. M/P		
2								
3								
L/H					19-	Ailerons		
E 1				"	22	& Flaps		
2								
3				Elec.	13-15	Fuselage		
F 1								
2								
3				"	7	Cockpit		
G 1								
2				Inst.	13-15	Fuselage		
3								
H 1								
2				"	7	Cockpit		
3								

Fig. 4. British Overseas Airways Corporation, Inspection Branch, Argonaut. R.R. Merlin, 626/1 engines.

check are selected on the basis of hourly life where this is the determining factor, or otherwise hangar convenience. Additionally, a simple chart is maintained to avoid the conjunction of major tasks which could cause labour congestion in any part of the aircraft or, for other reasons, could not economically be undertaken concurrently. Likewise, conjunction of tasks which would spread specialist labour strength too thinly is avoided.

The last three figures also indicate the division of the overhaul tasks into part "geographical" and part system and functioning.

Component overhaul times on even the well developed Constellation are still being reviewed and improved. Some work, even if it be no more than the inspection of structure or fixed components of systems, is done, against ultimate standards at too short intervals. The 6,000 hours between checks on the Constellation 049 main planes compared with 3,600 hours for a corresponding check on the later Argonaut, gives a measure of the progressive economies that can accumulate with operating and maintenance experience.

3.4. The General Trend of Progressive Overhaul

The broad economic advantages of Progressive Overhaul are obvious, but it is difficult to show direct cost comparisons because the aircraft types vary so completely and the procedures have developed over years; records indicate that a Progressive Overhaul probably will be completed with about 75 per cent. of the effort previously required for an annual C. of A. This is based on the lowest figures recorded in the past; and this lower percentage is now spread over about two years instead of one, so that ideally there should be an annual reduction of at least 50 per cent. in overhaul man-hours as compared with the earlier methods.

The ultimate development of the procedure is the complete integration of maintenance inspection and overhaul and this objective is being pursued in the

Group No.	*Group*	*Overhaul Period (hours)*
1	Fuselage—Nose to 260 Station	6,000
2	Fuselage—Nav's comp., Crew's Rest Comp., Galley, Main Cabin (Also forward toilet on 749 type)	6,000
3	Fuselage—Nose wheel nacelle, forward cargo compt. centre section, rear cargo compartment	6,000
4	Fuselage—Toilet and lounges, fuselage aft of pressure bulkhead	6,000
5	Mainplane Port. Also nacelles, fuel tank, oil tanks	6,000
6	Mainplane Stbd. Also nacelles, fuel tanks, oil tanks	6,000
7	Tailplanes and Fins	6,000
8	Main landing gear Port and Starboard	4,200
9	Nose landing gear	4,200
10	Ailerons and Tabs, Aileron and Tab Controls	4,200
11	Elevators and Tabs, Elevator and Tab Controls	4,200
12	Rudders and Tabs, Rudder and Tab Controls	4,200
13	Flap Controls, Port. Also centre section controls	4,200
14	Flaps and Controls—Stbd.	4,200
15	Engine Controls—Port	4,200
16	Engine Controls—Stbd.	4,200
17	Fuel System and Controls. Also dump valves and controls	4,200
18	Auto Pilot System	4,200
19	Electrical System—Megger Test	4,200
20	Radio Group A	
21	Radio Group B	
22	Radio Group C	
23	Radio Group D	
	The following is typical of the overhaul items added to a check 4:—	
	INSPECTION ROUTINE Items 5 or 6 — Items 3 or 4 8 — 9 13 — 12 18 — 18 19 — 19	

Fig. 5. Constellation type 049. Schedule of airframe inspection and overhaul periods.

600	1. Landing gear, L.H., R.H. and Nose removed and replacement fitted 2. Hydraulic system work in connection with above	B
1,200	1. Panel removal for control inspection and internal structure inspected as facilitated 2. Ailerons, L.H. and R.H. removed for bearing inspection 3. A/C control circuit, work in connection with above	C
1,800	1. Panel removal for main plane attachment inspection 2. Hydraulic system components removal and replacement 3. Panel removal for electric circuit testing 4. Electric circuit testing (1st electrical block)	D
2,400	1. Panel removal for control inspection and internal structure inspected as facilitated 2. Elevators, L.H. and R.H. removal for bearing inspection and refitted 3. Rudder removal for bearing inspection and refitted 4. Flight deck controls removal for bearing inspection and refitting 5. Electrical circuit testing (2nd electrical block)	E
3,000	1. Wing flaps, L.H. and R.H. removal for inspection and refit or replace 2. Hydraulic actuators for wing flaps removal and replacement 3. Anti-atmospheric system and pneumatic system units removal and replacement 4. Electrical circuit testing (3rd electrical block)	F
3,600	1. Panel removal for control inspection and internal structure inspected as facilitated 2. Panel removal for main plane attachment access and inspection as c/s and internal structure inspected as facilitated 3. Main plane, outer and tip sections removal for inspection (fuel system part survey is made possible) 4. Ailerons, L.H. and R.H. removal and replacement 5. Electrical circuit testing (4th electrical block)	G
4,200	1. Panel removal for fuel system inspection and collapsible tanks removal 2. Fuel tanks and system units removal for replacement 3. Fuel dump system units for replacement 4. Fuel flow test to Drg. LA-B.605	H
4,800	1. Panels removal for controls inspection and internal structure inspected as facilitated 2. Stabiliser bolts removal for inspection 3. Elevators and rudder removal for replacement 4. Tailplane and fin removal for structural inspection	J

Fig. 6. Argonaut (Merlin-engined "Canadair"). Provisional schedule of airframe inspection and overhaul periods.

closest co-operation with the technical staff of the A.R.B. The progressive steps to greater economy frequently involve not only the detail approval of work as airworthy, but also changes in formalities and regulations. For example, the Board recognises a satisfactory state of airworthiness by the formality of an annual renewal of the Certificate of Airworthiness, even though such reissue generally covers only a half-completed overhaul. Even as a paper formality, plus a functioning and performance flight test, this certification procedure imposes limitations on the approach to the ultimately desired procedures. In particular, the work carried out at Check 4 must be arranged and so recorded as to reveal for C. of A. records the difference between maintenance and overhaul.

In fact, with present overhaul techniques, the C. of A., once obtained by the aircraft manufacturer, should never expire except for change of ownership or in the event of major damage necessitating considerable reconstruction. Such a change in procedure would reduce much annual expenditure on paper work, simplify the overhaul and maintenance recording procedures and, at least, avoid flight tests at fixed calendar dates which bear no relation to necessity or best operational convenience. In this connection B.O.A.C. has recently negotiated with A.R.B. a change in the C. of A. flight test procedures, which saves several thousand pounds annually.

This is just an example of the minor steps to be taken in the development of the principles which B.O.A.C. now applies irrespective of the route, *i.e.* whether it be "Long Haul" such as U.K.-Australia, or relatively "Short Haul" such as U.K.-New York. It is recognised that on some short routes, with seasonal peak traffic loadings, there may still be a case for taking the aircraft off service for an annual overhaul during the slack season. These conditions do not apply to B.O.A.C.

It is not too far fetched to suggest that this general approach to overhaul might gradually develop for major sub-assemblies such as the engine. Full economic analyses, for example, might prove it possible and justifiable to design some turbines for the ready removal not only of the combustion chambers, but also of the power rotor, thus allowing the longest possible life to be obtained from the main carcase of the engine and the compressor. This would give incidental reductions in the capital value of spares holdings and in maintenance handling and transport charges. One major American airline applied this principle to the large reciprocating engines in their Boeing Stratocruisers; on this basis the operator held the normal minimum of spare power plant assemblies and accessories, but the overhaul float of spare engines was largely replaced by spare back and front cover assemblies only. The block changes on liquid-cooled engines are a close approach to this procedure.

The economics of such proposals are not simple and involve close study of the operator's overhaul and assembly facilities, transport charges and manufacturer's overhaul procedures, and so on.

4. OVERSEAS MAINTENANCE

B.O.A.C.'s overseas engineering staff and spares holdings have by no means increased in accordance with the greater complexity of modern aircraft and their operations—but the requirements are still heavy.

On the average, only two European contract staff are posted to normal refuelling halts, to assist with refuelling and any emergency minor maintenance. But this number would be increased to six or more where there are a large number of services with several types, as for example, Karachi, where there are about nine to handle Argonauts and Constallations for refuelling, minor checks and any emergency engineering problems, such as engine or airframe defects. Likewise at Cairo, where there are nearer twelve for Hermes, Argonauts and Constellations.

The order of such numbers might be better illustrated by saying that for the Hermes route to South Africa, it was originally estimated that a total of 19 contract European engineering staff would be required, distributed over seven stations. These numbers, of course, relate only to specialists on the aircraft electrical systems, power plant, and so on; in addition, there are local skilled tradesmen, cleaners and labourers, which in some places probably quadruple the local technical staff requirements.

In general, spares holdings are limited to a minimum of maintenance assemblies such as power plants (for example, three Hermes power plants are distributed over the U.K.-South Africa route), and a relatively few miscellaneous items such as sundry power plant accessories, spare tyres, minor items of electrical equipment, some instruments, undercarriage jacks and, where applicable, engine derricks.

Some overseas staff and supplies requirements are only temporary, for as experience is gained with new aircraft types, and reliability is established, it becomes possible to bring them back to the proper position at the main United Kingdom base; and overhaul planning and purchasing is based on this assumption.

While it would be wrong to attribute the control of overseas expenditure to Progressive Overhaul, the frequent overall system and instrument checks which it inevitably introduces in comparison with the annual overhaul are certainly contributory. However, the main factors have been

(*i*) Developments in speed and range which have so reduced elapsed times that, with increasing reliability, most engineering work can be carried out at the main base.

(*ii*) The development and approval of three-engine ferrying technique which further reduces the number of spare power plants overseas.

(*iii*) The development of the staff and resources of associated companies overseas, such as East African Airways, South African Airways, Qantas, and other concerns to whom routine over-

hauls can be sub-contracted on a regular basis, and who have the equipment and staff to deal with emergency repairs. (Although the local staffs of competing airlines often assist one another.) This aspect emphasises the importance of the desire for international standardisation of service couplings and component details to facilitate the development of common-user ground equipment.

An important development, made possible by (*i*) and (*ii*), is the employment of outside service organisations which, at overseas transit stations, supply servicing to all operators passing through. This so spreads the costs and reduces the charges on any one operator that it is now a regular practice at a main transit station, *e.g.* Gander on the New York service; and this system may well be introduced to other important transits on the international trunk routes.

5. MAINTENANCE PLANNING

A review of overhaul and maintenance cannot be limited entirely to generalities and the following outline of some detail procedures may be of interest.

5.1. Objectives

Compared with other forms of engineering and transport, or even aircraft construction, the maintenance and inspection of commercial aircraft is a complex and apparently untidy business. Large numbers of components, often installed in the most convenient order for construction must be reached, inspected or changed, and sometimes rectified, in the shortest possible time. This used to mean that the maximum number of tradesmen tried to converge on too cramped a space in the effort to adhere to the maintenance programme. Failure meant that operations schedules could not be kept and the airline became inefficient to its customers; or uneconomic measures, such as the introduction of standby aircraft, became necessary. To deal with a similar problem, the R.A.F. pioneered systems of Planned Maintenance, which most large air transport organisations have developed and modified to suit their particular requirements.

It might be said that all maintenance is planned and that in its most elementary form, Planned Maintenance does no more than take the daily plan out of the foreman's mind and the hourly wrinkles off his forehead and put them on a chart. However, the present applications go well beyond that. Mr. Ferguson, of B.O.A.C.'s engineering staff, writes in the "Journal" of the Licensed Ground Engineer's Association:—

> "The prime object of Planned Maintenance is to knit the work of all skilled tradesmen engaged on an aircraft routine check into a clear-cut pattern, thus eliminating congestion and interference, whilst at the same time making provision for control of supplies, equipment and any other factor which may effect maintenance efficiency."

The planning resultant from this prime objective is sufficiently specialised to justify a Planning Office at each Base; in fact, a new conception of the "Planning Engineer" is being evolved. The scope of this branch of airline engineering is very wide because Maintenance Planning incorporates the scheduling and timing of the Progressive Overhauls, and the flow of supplies, consumable spares, and so on. In B.O.A.C. the term covers:—

(*a*) Planning of the A.R.B. approved inspection schedules which are, or will be, applied to all major routines, and, where economically justified, the planning of the minor Checks, *i.e.* 1 and 2.

(*b*) Planning the superimposing of Progressive "Certificate of Airworthiness." Overhaul on the Checks 4.

(*c*) Planning supplementary work, such as the routine replacement of time-expired items.

(*d*) Planning the incorporation of modifications within the time allowed for the routine checks.

(*e*) The directions to Line Supplies Officer regarding requirements for:—

routine checks;
replacements at overhauls;
supplementary time-expired items;
minimum float for unpredictable items.

(*f*) In conjunction with the Operational Planning Sections, the selection of particular aircraft for particular services so as to ensure that no major routine overhaul occurs overseas and that all available hours between routine overhauls are used.

There should be no misconception of the staff requirements for the planning work.

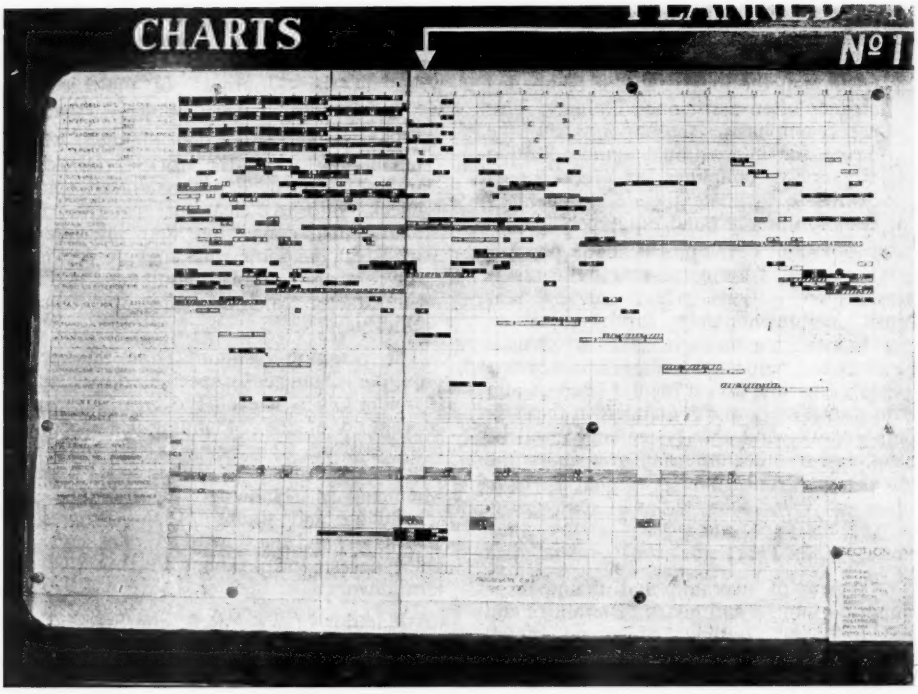


Fig. 7.

They are not excessive; an average figure would be less than one per cent. of the total base engineering staff.

5.2. Planning procedures

Taking as an example the planning of a major routine overhaul, the outline of the procedure is as follows:—

Master Schedules have been prepared in which all tasks for particular routines or sections of overhaul, are indexed and cross-referenced both to aircraft component and system locations charts, and to A.R.B. approved schedule of inspection duties.

A list of the routine check items is drawn up from the Master Schedule or, in its absence, existing inspection schedules. This list is categorised under the trades concerned and the normal time for each item is assessed; (this last is time-fixing, based on the average time—it is not rate-fixing.)

These, and other items of routine work which it is proposed shall be undertaken during the aircraft check, are plotted on a provisional master chart against "time" and "location," and time and space allowance is made on this chart for rectification work or modifications. Other factors considered are work when the aircraft is jacked up, avoidance of conjunction of work such as electrical and fuel system checks, or the timing for the location of ground equipment such as jacks, engine derricks and trolleys, and so on.

The appropriate section of the C. of A. overhaul programme is not incorporated in the chart for the Check 4 maintenance routine because operational convenience may lead to changes in the overhaul sequences and, furthermore, each overhaul sequence is different. Instead, a supplement chart is drawn up for the overhaul section and added to the main chart as required; thereafter, the treatment is the same as for the concurrently running routine, except for the additional overhaul records. Modification programmes, supplementary items, unscheduled engine changes, and so on, are treated similarly.

The complete disposition chart then shows at a glance for how long, and by whom, each area of the aircraft will be occupied during the routine. All trades are represented. Usually each is allotted a key colour, and the complete chart will be cleared (during preparation in the planning office) on any interference between operators. Fig. 8 shows a section of such a chart.

Corresponding with the chart representation of item times, a complete set of operations cards with the task reference numbers and trade reference letters is drawn up, one for each tradesman, leading hand and inspector, defining in accordance with the particular routine and the responsibilities of that individual, the detail of each task and the time allowance.

A set of inspection sheets is prepared covering the items which must be cleared in the rectification periods. In some cases, it is Inspection responsibility only to confirm that functioning checks, and so on, have been carried out. This represents a form of quality control in which the inspector is responsible for and signs for a zone or location and not for each detail of work in that zone. However, the inspector's signing-off sheet is cross-referenced to the Master Schedule, the tradesman's name and the task card reference letter and number, so that responsibility is properly defined. Essentially, therefore, the licensed inspector's responsibilities are properly concentrated on airworthiness matters; this saves considerable time and limits the licensed inspection staff to a specialised group, averaging less than 10 per cent. of the engineering staff.

The chart, operations cards and work sheets are discussed with representatives of each department concerned and each trade representative contributes to any changes which may appear necessary. When agreement has been reached, the chart and operations cards are finalised and a hangar trial is carried out on the next routine overhaul due. Changes are then introduced as required and thereafter the chart becomes standard for that check on that aircraft type, except that adjustments may be progressively introduced as experience is accumulated.

A blank work progress chart is also prepared, against the same time base as for the master routine chart, and on which operator's names are listed against the trade letter references used for the master routine chart. The task reference numbers are marked progressively against name and time and checked off as the work progresses (Fig. 7).

A specimen master chart for Check 4 is shown. The letter references and colours on the left hand side and in the body of the chart define the type of work.

The chart in relating trades, zone availability and tasks, also defines the team strength required for the routine.

The spaces between the coloured patches represent the allowances, in time and space availability, for inspection and rectification work.

By dovetailing the tasks and rectification periods, a "float" of tradesmen becomes available at various times for rectification. The bottom of the chart can also be used to show when power is required or when special handling and jacking equipment must be on hand, generally several hours before the time scheduled for the job.

It is obvious that the details and scope of charting and progressing, and so on, can be varied within wide limits, but the essentials are the pre-planning and dovetailing within time and space, of tasks and locations for a standard routine or overhaul sequence; in the procedures described the most important charts and documents can be summarised as follows:—

(*i*) Master schedules detailing tasks for the routines and overhaul sequences.

(*ii*) A standard routine chart indicating trade letter reference, zone availability and rectification and inspection periods, plotted against time and aircraft zone.

(*iii*) Charts for overhaul sequences, supplementary items, and so on, which are attached to (*ii*) above.

(*iv*) Cards detailing individual tasks and time allowances.

(*v*) A work progress chart plotted against time and staff names and letter references.

(*vi*) Inspection documentation.

(*vii*) Documentation as necessary to ensure availability of components, supplies and special equipment in accordance with the planned programme.

When the charts and tradesmen's cards have been established, subsequent routines and overhauls are entirely under the control of an aircraft supervisor with his team of leading hands and inspectors. The supervisor reports only to the hangar foreman who

ensures the availability of staff and equipment in agreement with the Engineer Superintendent of the Line. (There is thus a minimum of "walking" supervisory staff.)

Normally, the standard routine task chart and the work progress chart are mounted adjacent to the aircraft, on a lectern which is surmounted by a clock calibrated to at least 24 hours. The clock is started at zero, at the beginning of the routine and, until the completion of the routine, is switched off only during the standard break periods. Vertical cursors are superimposed over the routine and work progress charts and are moved along the time scale in synchronisation with the clock. This enables the maintenance of programme to be checked at a glance and likewise the proper disposition of tradesmen at various times can be checked or any individual immediately located. The lectern, under the control of the aircraft supervisor, is therefore the control centre for the routine (Figs. 8 to 10).

If unexpected defects or inspection snags are encountered, it is the responsibility of the aircraft supervisor to call in specialists available for rectification work, and adjust the programme as necessary.

The matter of "unpredictable" items is vital and unless the man in charge is capable of utilising the basic flexibility of the system, the unexpected could break any programme.

It is, therefore, important that the planning engineers, inspectors and leading hands are specialist to the type of aircraft on which they are working and are familiar with the records and signs of probable faults—that is, they are normally associated whole time with a particular type of aircraft and operating Line.

The same problem applies to time-expired components; items can be inserted in the standard routine schedule to cover the provisioning and changing of items which records show will be time-expired. However, intelligent anticipation and knowledge of casualty rates are necessary to ensure the correct preloading of hangar stores and the avoidance of supplies delays.

It is possible to prepare provisional programmes for new aircraft not yet introduced into service; for this purpose inspectors and maintenance and planning engineers are sent to co-operate with the manufacturers and prepare provisional routine and overhaul charts and trial operation cards, and so on. These are progressively modified after the aircraft comes into service.

5.3. Rectification and Stores Procedures

Although the standard routine charts allow time for rectification, this term covers only inspection, system adjustments and component replacements. It is basic to Maintenance that only the minimum of rectification of removable component faults is attempted on the aircraft during the inspection routine. Any faulty component is removed and despatched to workshops where the decision is taken as to local rectification or return to manufacturers. Even local rectification of a faulty component means an ultimate passage through stores, while the aircraft on routine is re-equipped from stores. For this reason, the preparation by the planning staff of schedules for preloading hangar stores is important.

Naturally, the procedure reveals immediately where potential delay in the programme might arise because of a supplies problem, and hence leads to the utmost co-operation between the supplies organisation and the hangar or Line stores. It also emphasises the need to integrate programmes in the component overhaul shops closely with the Maintenance plans in the hangars.

It is essential that specialist leading hands possess particularly good system knowledge so as to ensure that any particular component causing trouble in a complex system is located. Failure can too often lead both to repetitive faults and unnecessary component overhaul.

5.4. Pre- and Post-Routine Checks

It is important, particularly on Check 4 plus overhaul, that hangar work be commenced and completed expeditiously; there is, therefore, before every Check 4, a time allowance for outside checks on those items requiring engine power, *e.g.* flap operation, electrical system, fuel system. A similar allowance is made for post-routine and overhaul functioning checks on the tarmac.

5.5. Direct Advantages of Maintenance Procedures

Before the introduction of the procedures outlined, a Check 4 plus overhaul on a Constellation 049 varied between 6,600 and 7,400 man-hours, dependent on the work to be done. With the detailed control of time and space, it has stabilised at 5,500 $\pm$ about 150

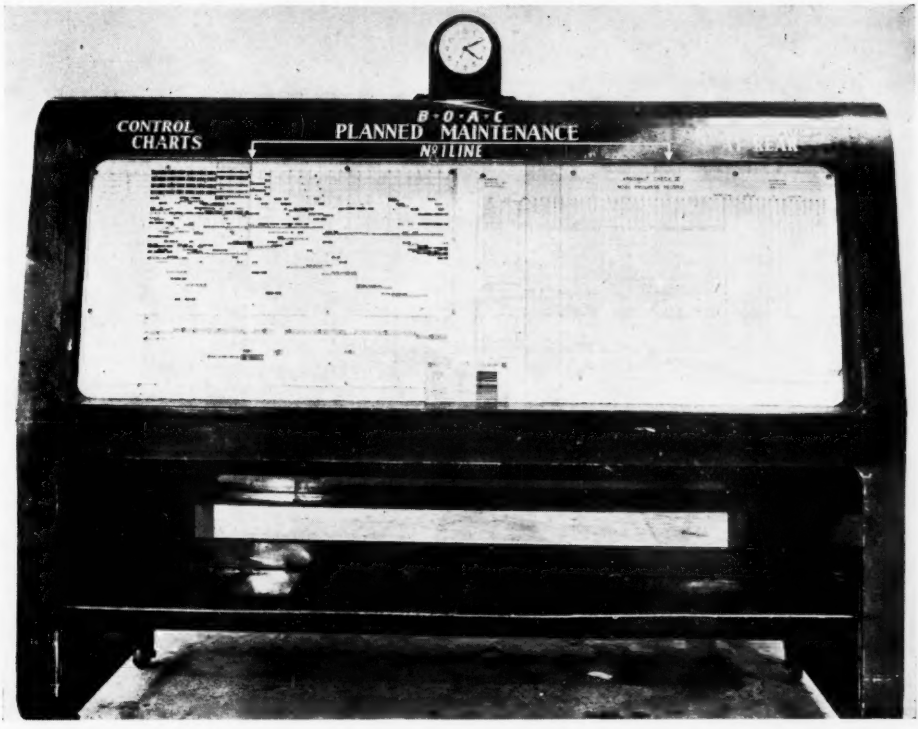


Fig. 8.

man-hours. Possibly this stability of time and labour requirements provides the major contribution to operational planning and staff economy. But the pruning of the rectification time, which is closely associated with the space control, and the planning of the overhaul sequence to take advantage of the system overhaul unavoidable with changes of time-expired items, gives progressive economies.

5.6. General Advantages of Detailed Procedures

The Maintenance Procedures worked by B.O.A.C. offer a number of general advantages and improvements in working conditions which are appreciated by all hangar and workshop staff. Some of these points are:—

(*i*) The Leading Hands, who actively work on the job and do not just supervise, report to the aircraft supervisor and are responsible for the progress of their team mates and the maintenance of the planned programme; without their fullest co-operation, the programme cannot be maintained. Since they take part in the original planning, they see the complete picture of the progress of the routine in accordance with programme.

(*ii*) Long-term planning of the programme can avoid wide scale week-end work (although this will not apply as aircraft utilisation reaches a maximum). Similarly it generally avoids last hour rushes and the need for unplanned night-shift.

(*iii*) The skilled tradesman does not have his initiative cramped. Instead he knows that he has a given space and times in which to complete the job and that he will not be irritated by others trying to get at something nearby.

(*iv*) Irritating and expensive delay while

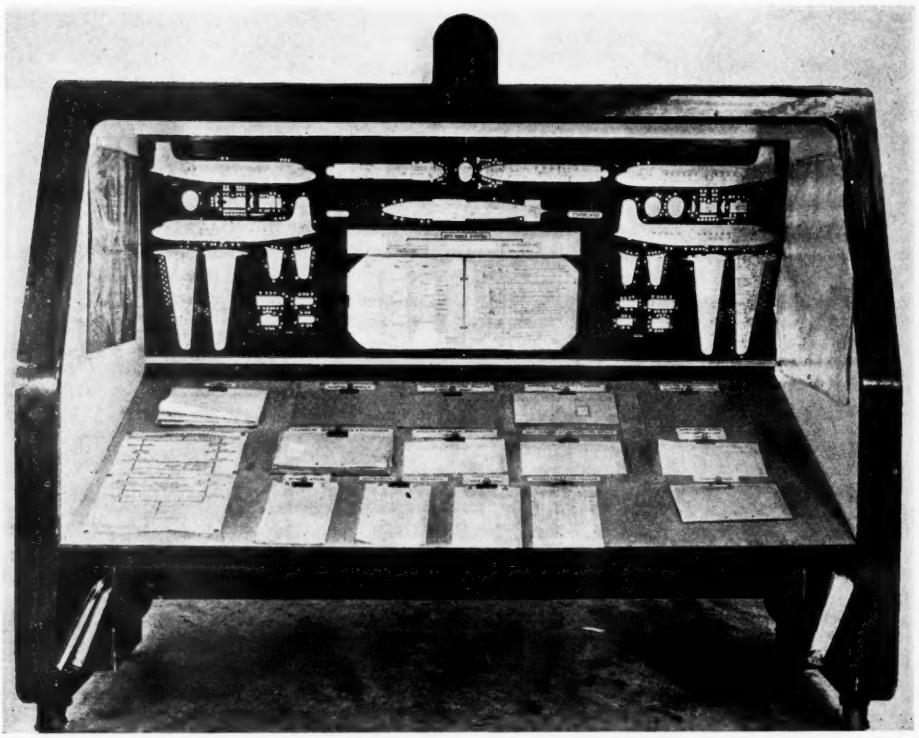


Fig. 9.

waiting to get at a particular task is avoided.

(*v*) Each man works as a member of a team to a clearly defined programme, and this helps to ensure smoother working for all on the job. Typical team make-ups are shown in Fig. 11.

(*vi*) The careful planning ensures each tradesman a variety of tasks and avoids his specialising on jobs confined to one part of an aircraft or its installations, (though some airlines working a similar system tend to demand greater specialisation).

(*vii*) The system of quality control at inspection helps to widen the scope and responsibility of the unlicensed tradesman and leading hand.

(*viii*) Overall improvements of a maintenance routine generally come from indications that time for rectification is excessive; or from more efficient dovetailing of programme details as shown possible by experience. These are generally more valuable sources of time saving than attempts to adjust the averaged time-allowances for a detail engineering task.
In fact, the major time savings depend, as they should, on the planning as much as on the efficiency with which an individual task is carried out.

The detailed planning does not impose new licensing requirements; so although the usual classification of trades must be maintained, possession of a licence is not essential and any tradesman can, by virtue of ability and versatility, rise to Leading Hand and upwards.

Of course, licensed engineers are necessary for inspection duties. However, the authority to select inspectors and approve work is at present vested by the A.R.B. in the Chief Inspector of any particular Line, so that even in this specialised field the close co-operation with the A.R.B. reduces external controls to

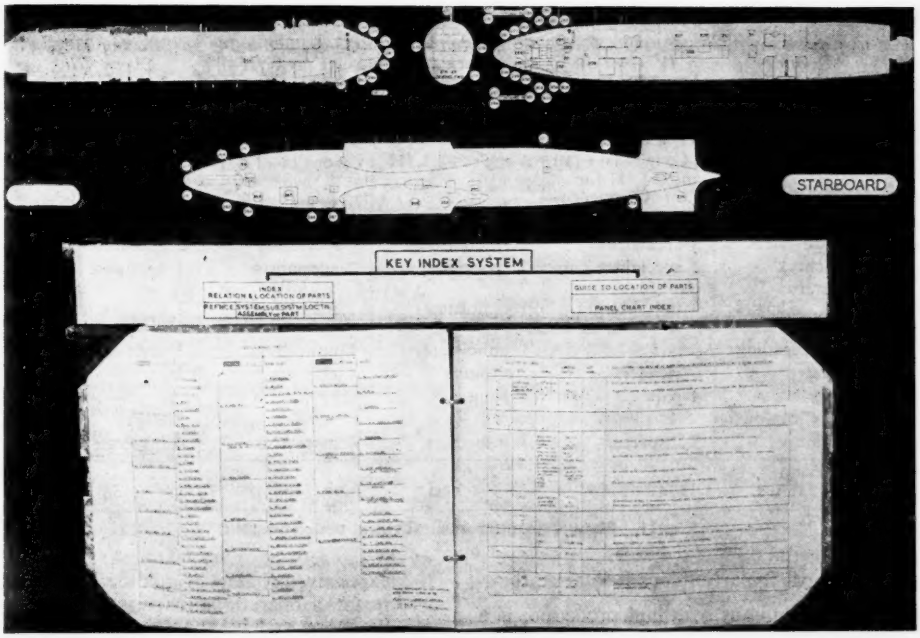


Fig. 10.

the minimum and allows recognition of the responsibility of the individual.

From the point of view of personnel or licensing there is, therefore, no bar to the steady integration of maintenance checks and overhaul into a continuous process.

These practices are now widespread in the air transport industry. For example, a visit to the main P.A.A. base at Miami, will show very similar procedures, and almost identical problems are encountered, not only on detail, but on issues such as responsibility for supplies, the best way of dealing with component overhauls, the pre-loading of local small parts stores at the equivalent of "control lecterns," and so on. (Similarly, on the United States domestic Lines, an article in "Aviation Digest," dated 22nd October 1951, revealed that Braniff Airlines, based at Dallas, are concerned with the same problems and reaching similar solutions.)

5.7. Maintenance Docks

The case for "docking" an aircraft completely inside fixed work stands is still under review. Movable work stands for, say, access to installed engines can generally be designed with a sufficient degree of adjustment to suit a range of modern aircraft, and for operating emergencies such as an unscheduled engine change, without interference with other work. Fixed docks might prove too inflexible for this work and would impose the double cost of both docks and movable work stands.

The advantages of docks are well recognised so that B.O.A.C. are examining various schemes for application in the new hangars at London Airport. However, a comparison with, say, manufacturer's production jigs would not be completely valid. Transport aircraft are flexible in their application, and no system of docking for maintenance should be so expensive and "rigid" that it could not economically be adapted to varying operating plans and maintenance techniques during the many years of operating life of a fleet of aircraft.

6. FUTURE TRENDS

6.1. Special Maintenance Procedures and the equivalents of Progressive Overhaul must have been developed for most forms of transport operations. The following six

Aircraft and Routine	*Constellations 049/749 Check IV C of A sequence*	*Constellation 049 Check III*	*Constellation 749 Check III*	*Boeing 377 Check III*
Task				
Engine check	6 eng'rs+2 L/H	8 eng'rs+1 L/H	12 eng'rs+1 L/H	12 eng'rs+1 L/H
Airframe check	14 eng'rs (+6/10 and 3 L/H for C of A sequence)	6 eng'rs+1 L/H	6 eng'rs+1 L/H	7 eng'rs+1 L/H
Instrument check	2 specialists	2 specialists	2 specialists	1 specialist
Electrical check	3 specialists	2 specialists	4 specialists	5 specialists
Radio check	2 specialists	2 specialists	2 specialists	1 specialist
Upholstery Repairs	3 upholsterers	1 upholsterer	1 upholsterer	1 upholsterer
Upholstery Cleaning	—	1 upholsterer	1 upholsterer	3 upholsterers
Cleaning	6 cleaners	2 cleaners	4 cleaners	—
Painting	4 painters	1 painter	—	—
Engine Cleaning	—	—	—	2 eng'rs
Inspection	5 inspectors	3 inspectors	4 inspectors	4 inspectors
Total Team Strengths	47+9/15	30	38	38

Fig. 11. Planned maintenance. Typical team strengths.

points are particularly relevant to aircraft:—

(*i*) The continuous overhaul procedure is a necessity because the expensive modern aircraft must not be wasted on unnecessarily long, non-revenue earning periods on the ground. More work must be done by fewer aircraft.

(*ii*) Present and projected aircraft have such speeds that no matter how long the route all major routines can be concentrated at the home base. However, to obtain the full value of future high-speed aircraft, they must be regarded as units of a high-speed conveyor belt. On future operations, that may introduce problems of passenger handling, with stop-over facilities, and so on; but, correspondingly, the home-based maintenance and overhaul procedures must be developed to the fullest extent.

(*iii*) Because of the steady increase in the individual life as well as the competitive life of any given aircraft type, detailed studies of aircraft component and structural life are becoming necessary. The life of main structural components must not be less than the competitive life of the type.

(*iv*) The overhaul life of individual components must be extended more by thorough testing in the design and development stages rather than by the expensive progress of modification as the result of operational experience. It must be more widely appreciated that component overhaul at too frequent intervals as the result of poor design and manufacture, or because of too rigid "airworthiness procedures," is not only expensive in itself but adds to the detail complication and overheads of the overhaul organisation.

(*v*) Aircraft layout and installations must be planned with an eye to the first essential of maintenance and overhaul; *i.e.* the avoidance, as far as is practicable, of the conjunction of major components of different types of systems so as to allow concurrent work on different systems. Associated with this requirement is ease of access to system components and vital structural features.

(*vi*) Direct airframe maintenance and overhaul costs, that is man-hours, replacement parts and material, may total six to seven per cent. of the direct operating costs. Design for greater economy, therefore, will be a significant factor in directly reducing costs as well as increasing utilisation.

The better these points are appreciated in the initial design, the more readily the operator will be able to develop precise and economic procedures; and the degree of

precision will determine the accuracy with which it is possible to establish the most suitable layouts and locations of hangars, workshops and stores for this untidy business of giving numbers of engineering specialists and tradesmen access to different parts of a compact and complex unit.

It is possible with proper estimation of time and space requirements, to predict how many hangars are required, with a given fleet of aircraft, to ensure the production of the required number of seat-miles or ton-miles per year. B.O.A.C. has examined many such combinations in terms of future aircraft and their probable cruising speeds and payloads, in arriving at their overall requirements for new hangars and workshops at London Airport.

Naturally, overhaul and maintenance procedures will determine many organisation details of a main overhaul base. The following five obvious facts are probably at the back of most maintenance organisations.:—

(*i*) The ultimate development of Maintenance Routines and Progressive Overhaul for any aircraft type and operation needs specialist planning by engineers working closely with the operations staff and maintenance engineers responsible for that aircraft type and operation.

(*ii*) Given a central base such as London Airport, then, in the interests of overall economy, it is desirable for the tradesman, if not the leading hands and inspectors, to be able to switch readily from one type of aircraft to another, incidentally adding to his own experience and future scope.

(*iii*) The main "production" task of maintenance and overhaul requires an outlook and approach differing from that for route servicing and the shorter inspection routines which are conducted away from the main base or on the tarmac.

(*iv*) Component replacement and system adjustment must be made on an aircraft on routine; but component rectification on an aircraft is not economic and must be handled by electric, electronic or hydraulic specialists, as appropriate, in special component overhaul workshops.

(*v*) Component overhaul programmes and supplies must be worked out in terms of the Planned Maintenance and Overhaul requirements. Economies and operational planning demand that they be properly matched, and aircraft performance and control requirements necessitate the closest collaboration on standards.

Hence one might forecast a Central Maintenance Base for several Lines under the control of a Base Superintendent. But for each Line and aircraft type there would be an Engineer Superintendent with full maintenance and overhaul responsibility. Working with each Engineering Superintendent there would be planning engineers, aircraft supervisors, leading hands and inspectors, all specialist to the Line and type of aircraft.

The main maintenance strength would consist of tradesmen who are essentially installation engineers. For overall economy and staff interest, it might be possible to meet Line peak requirements by allowing tradesmen to switch from Line to Line. But rather than split maintenance teams, the component overhaul workshops might be regarded as the best emergency source of specialists for rectification work at peak loadings.

Serving all Lines under the control of the Base Superintendent, would be all ground equipment that is not special to particular aircraft, the component overhaul workshops, the main stores and local transport. All of these could be physically separate from the Maintenance Hangars, but there must be stores for each Line in the Line Hangar and under the control of the Engineer Superintendent and his aircraft supervisors; the preloading for maintenance and the planned flow through these local stores will establish the programmes for the component overhaul workshops.

6.2. Component Overhaul

Discussion of component overhaul workshops always introduces one question; to what extent, if at all, should the airlines subcontract component overhaul to the manufacturer? The purchase of new equipment always raises this question, whether or not the operator already possesses component overhaul equipment and trained staff.

One can dismiss the "emotional" approach, which is that the operator must take full responsibility for airworthiness. This is not, and could not, be possible until a new type of aircraft has been in service for several years, and its faults eliminated and characteristics known; but even then the

responsibility for airworthiness is still shared with the manufacturers and the airworthiness authorities.

The routine overhaul of standard instruments, electrical components, and hydraulic system components, and so on, is probably best handled by the operator, otherwise transport and supplies procedures become too expensive and complex. In these instances, the manufacturer's part is best played by close liaison with the operator.

However, the case of some major sub-assemblies is more doubtful; for example, the more complex electronic instruments and auto-pilots, cabin pressurising equipment, propellers and engines, particularly turbines, and so on. In such instances, it is sometimes questionable whether the operator would be justified, for several years after the introduction of new equipment, in setting up additional and expensive overhaul facilities and procedures which are liable to be changed because of equipment modification during the development period. Moreover, it is possible that in normal times the design and production of new civil equipment and its progressive development to peak efficiency could be financially practicable only if the manufacturer had substantial overhaul contracts to back up his development and production effort.

Experience of sub-contracted overhaul has shown that sound commercial agreements can be reached to the mutual satisfaction of operator and manufacturer. Naturally, such contracts necessitate the knowledge, on the part of the operators, of what is possible and reasonable as a maximum overhaul "life."

Whatever the overhaul procedure, the operational life of equipment such as auto-pilots, power plants, and even of the whole aircraft, might be divided into three periods:—

Firstly: an extensive development and rectification period to attain maximum reliability;

Secondly: a period of infrequent modification to increase performance and economic value; and

Thirdly: a period of maximum economic value and routine running during which there is virtually no development or modification action.

It may be that combined overhaul and development contracts are required for the first period and that the operators take over for the second two periods. The manufacturer then would be free during the later stages to digest operational experience and plan for successor equipment, while continuing overhaul contracts with smaller operators who do not wish to be saddled with the overheads of specialist overhaul workshops. Incidentally, the manufacturer's experience of contracting on overhaul costs often has good resultant effects on component design.

Going further, component overhaul might be sub-contracted throughout the commercial life of the equipment. The operator could then concentrate on operating and selling air transport, and confine airline engineering work even more than at present to the maintenance of airworthiness by inspection, system adjustment and component replacement. There is no simple answer to such questions and each range of components must be considered in terms of the problem offered and the operator's overhaul facilities. However, the existence of the questions confirms that component overhaul, rather than the now well-developed procedures for airframe maintenance and overhaul, present a field for design and planning towards lower engineering costs.

The 1952 Garden Party

THE Society's Thirteenth Garden Party was held at White Waltham Aerodrome, near Maidenhead, on Sunday 15th June 1952 and was attended by some 3,000 members and guests. Although the weather was not the perfect June day for which we had hoped, it was an improvement over the previous year, being warmer, with sunshine for the flying programme.

Because of the later date the Garden Party (this year) came at the beginning of the President's term of office; members and guests were received by Mr. G. H. Dowty, F.R.Ae.S., and Mrs. Dowty. Before flying began the President toured the enclosures in a three-wheeled A.C. car of 1909 vintage driven by Mr. F. H. Parker. He also spoke to those taking part in the flying programme and thanked them on behalf of the Society.

Music was provided during the afternoon by the Fairey Aviation Works Band conducted by Mr. H. Mortimer, O.B.E.

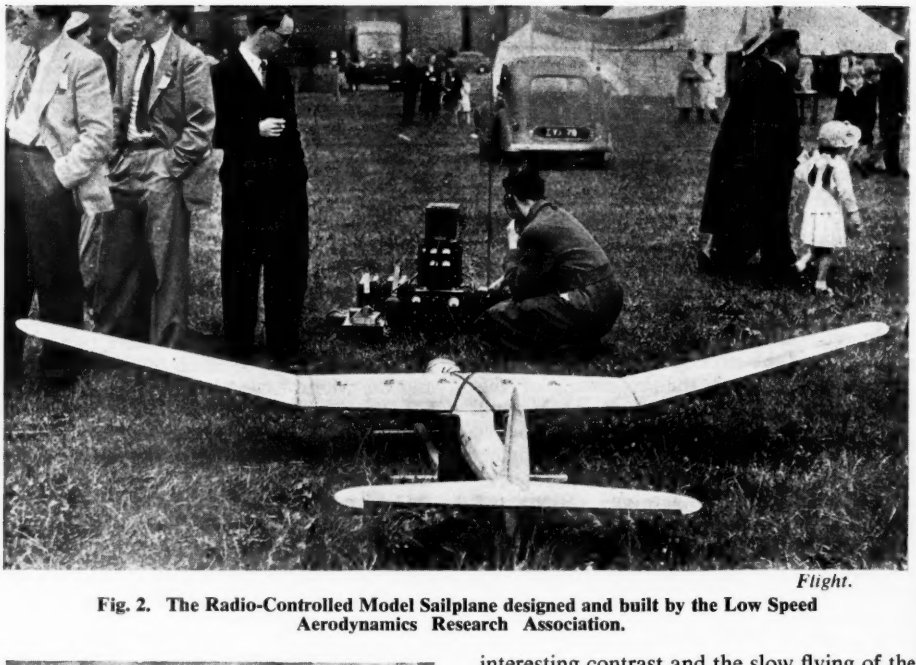
There were no balloons nor exciting novelties in the flying programme but three helicopters, two gliders, a model glider and a number of light aeroplanes, delightfully flown by "sporting" and test pilots, provided a quiet and leisurely aeronautical background for this annual reunion and "get-together" of new and old friends.

The three helicopters, each of a different type, aroused much interest and the Westland Sikorsky S.51 gave an amusing display of the versatility of the helicopter assisted by Lieut. Commander J. S. Sproule, R.N., with his folding motorcycle. Gliding, always popular, was represented by a Sedbergh two-seater glider which was towed off by a Tiger Moth, and the Meise towed by the Fieseler Storch. Mr. Furlong, in the Sedbergh, with an A.T.C. cadet, gave a running broadcast of gliding instruction, and Lieut. Commander Goodhart gave a display on the Meise.

On the aeroplane side the Prestwick Pioneer demonstrated its slots, slats and flaps by clearing a "hedge" in less than 100 yards after take-off, the new Aiglet trainer seemed to specialise in stall turns and the Tipsy two-seater and the little Fairey Junior were most effective. As always, the little Comper Swift aroused much interest and the Hawker Cygnet, although nearly 30 years old, proved that in spite of its age it is still one of the most successful light aeroplanes ever built. The de Havilland Beaver and Chipmunk, flying together, made an

Flight.

Fig. 1. Part of the crowd with one wing of the Sky Sailplane in the foreground. The group on the left includes Mr. and Mrs. P. G. Masefield and family, and Captain A. G. Lamplugh.



Flight.

Fig. 2. The Radio-Controlled Model Sailplane designed and built by the Low Speed Aerodynamics Research Association.

The Aeroplane.

Fig. 3. The Westland Sikorsky S.51 taking on board a crate of beer after de-canting Lieutenant-Commander Sproule and his folding motor cycle, which may be seen immediately under the crate. On the left is the 1909 A.C. in which the President toured the aerodrome, and which delivered the beer to the S.51.

interesting contrast and the slow flying of the sturdy Beaver seemed almost to rival that of the Pioneer. The Fieseler Storch by way of diversion "lost" its propeller and emulated the gliders on landing, while the SAAB Safir, an attractive Swedish three-seater, showed its range of speed.

There was disappointment at the non-appearance of the Miles Aries (which had to return to Redhill with undercarriage trouble), the Cessna 190 which had been coming from Switzerland, and the Taylorcraft, but an Aeronca ably replaced the latter and Mr. Fricker put the always amusing and interesting Zaunkoenig through its paces. The last item on the programme, and one which aroused many nostalgic memories (not only for the President), was a Gloster Gladiator, believed to be the only one of its type now in existence.

The most novel item on the programme and one which created much interest was the demonstration of the radio-controlled model glider designed and built by the Low Speed Aerodynamics Research Association.

Although there was no Static exhibition as such, the new British sailplane, the Sky, belonging to Mr. P. A. Wills and on which he won the World Gliding Championship

later in July at Madrid, was on exhibition and the centre of an admiring throng most of the afternoon. An Avro XIX specially equipped with radio as a flying class room for the College of Aeronautics was also on show. In addition a number of people came by air to the Garden Party and some 30 aircraft in the Visitor's Aircraft Park added many more representative types of light aircraft.

An informative description of events was broadcast throughout the afternoon by Mr. B. J. Hurren, of the Fairey Aviation Co. Ltd.

White Waltham Aerodrome was again lent for the occasion by kind permission of Sir Richard Fairey, M.B.E., Hon. F.R.Ae.S., and the Ministry of Supply, to whom the Council of the Society is greatly indebted.

The Council is particularly grateful to Sir Richard Fairey, Past-President of the Society, and to the Directors and Staff of the Fairey Aviation Co. Ltd. for their generous and practical help, not only on the day of the Garden Party, but during the many weeks of preparation and organisation. Group Captain R. G. Slade, Chief Test Pilot of Fairey Aviation Co. Ltd., was in charge of the Flying Programme, and the Council pay special tribute to him and to his assistants, Miss J. Somerville and Mr. V. G. Robb, for their invaluable assistance.

Without the enthusiastic and generous co-operation of the pilots and ground crews, a "flying" Garden Party would not be possible and the Council appreciates sincerely their help.

The Society is greatly indebted also to the many private owners and to the following for making the aircraft available: The Air Ministry; Association of British Aero Clubs and Centres; Auster Aircraft Ltd.; Bristol Aeroplane Co. Ltd.; British European Airways Corporation; British Gliding Association; College of Aeronautics; de Havilland Aircraft Co. Ltd.; Fairey Aviation Co. Ltd.; Flightways Ltd.; Hawker Aircraft Ltd.; Low Speed Aerodynamics Research Association; Royal Aircraft Establishment; Royal Navy; Royal Swedish Air Force; Scottish Aviation Ltd.; Slingsby Sailplanes Ltd.; Ultra Light Aircraft Association; West London Aero Services; and Westland Aircraft Ltd.

The Council wish to thank the Ministries of Supply and Civil Aviation, the Air Ministry, the London Air Traffic Control Organisation, and the West London Aero Club and the Home Command, Royal Air Force, at White Waltham, for their co-operation and assistance.

They also wish to express their appreciation of the assistance given by the de Havilland Technical School, and R.A.F. Cadets from Halton.

Dr. R. B. Body, British European Airways Corporation, was in attendance as Honorary Medical Officer during the afternoon, and to him also is due appreciative thanks.

The efficiency of the Royal Automobile Club, the Berkshire Constabulary and the British Legion in traffic and car parking arrangements was greatly appreciated and the Council also thank the St. John Ambulance and Nursing Brigade for their services and help.

The ready co-operation of the Pyrene Co. Ltd. in arranging extra fire fighting equipment and Tannoy Products (Sound Rentals) Ltd. for providing the sound amplifying equipment is gratefully acknowledged.

The success of the Society's Garden Parties depends greatly on the friendly help of the aircraft industry and organisations concerned with aviation in Great Britain, not only those named in these acknowledgments but many individuals in minor ways; to them all the Society is sincerely grateful.

The flying programme, which began at 3 p.m., was as follows:—

The Fairey Aviation Co. Ltd.

Fig. 4. A view taken from the air of the early arrivals. The visiting aircraft park is in the foreground.

Aircraft	*Owner*	*Pilot*
Prestwick Pioneer	Scottish Aviation Ltd.	N. J. Capper
Auster Aiglet	Auster Aircraft Ltd.	R. L. Porteous
Bristol Sycamore	Bristol Aeroplane Co. Ltd.	C. T. D. Hosegood
Zaunkoenig	Ultra Light Aircraft Association	John Fricker
Radio-Controlled Glider	Low Speed Aerodynamics Research Association	Flown by D. W. Allen Commentary by N. L. Walker
Tipsy B	Fairey Aviation Co. Ltd.	C. G. M. Alington
Hawker Cygnet	Hawker Aircraft Ltd.	F. Murphy
Aeronca		B. J. Snook
Sedbergh Glider	Air Ministry	E. J. Furlong
SAAB Safir	Royal Swedish Air Force	Captain S. G. Bissmarck
Bell Helicopter	British European Airways	Captain J. G. Theilmann
Comper Swift	A. L. Cole	C. G. M. Alington
Fairey Junior	Fairey Aviation Co. Ltd.	M. R. V. Morris
de Havilland Chipmunk	de Havilland Aircraft Co.	P. Fillingham
de Havilland Beaver	de Havilland Aircraft Co.	D. B. Taylor
Meise Glider	Royal Naval Gliding and Soaring Association	Lieut. Commander G. A. J. Goodhart
Fieseler Storch V.P. 546	Royal Aircraft Establishment	Squadron Leader J. L. Sowrey
Westland S.51 Helicopter	Westland Aircraft Ltd.	D. Colvin
Gloster Gladiator	Flightways Ltd.	V. H. Bellamy

REVIEWS

The following are reviewed:—

Structural Adhesives—The Theory and Practice of Gluing with Synthetic Resins
Synthetic Resins and Allied Plastics
Fundamentals of Automatic Control
Selected Government Research Reports, Vol. 5. Servo-Mechanisms
Advanced National Certificate Mathematics
Strain Gauges—Theory and Application
Carburation, Vol. 2
Design of Machine Members
Air Transport in Australia
The Air League Aircraft Recognition Manual
Tedder
The White Rabbit

STRUCTURAL ADHESIVES—THE THEORY AND PRACTICE OF GLUING WITH SYNTHETIC RESINS. Lange, Maxwell & Springer Ltd., 1952. 203 pp. 21s. net.

In September 1951 Aero Research ran a week's course on the technology of synthetic resin adhesives, during which lectures and demonstrations alternated. The formal talks have been collated in a well-produced book, which includes the diagrams and photographs that were used by the speakers.

There were two divisions to the course, one dealing with the applications of adhesives to the wood-working field, and the other with their use in engineering, electrical and allied industries. Introductory lectures, common to both courses, were given by four members of the Company's staff: Dr. de Bruyne dealt with the fundamentals of adhesion and cohesion, the basic structure and properties of cellulose and wood, and the nature and form of rubber and plastics. He gave papers on the true strength of glued joints and on specification and allied methods of testing adhesives. Hubbard and Scales spoke of the properties and characteristics of synthetic resin glues from the viewpoint of the user, and Raynor gave an excellent account of their chemistry, the clear and simple language of which deserves high praise.

In the wood-working course, six of the lectures were by Scales, who covered veneering, tapeless edge-splicing, the means of accelerating setting by heat, the extension and fortification of resin glues and difficulties in gluing and their remedies. The first five are straightforward accounts of recognised processes, but the last could only have been prepared by one having first-hand experience of industrial usages. Particular aspects of gluing processes were described by independent specialists. Ellison, of Hills, spoke of process control in plywood manufacture; Lacey, of the Forest Products Research Laboratory, on the heating by low-voltage high amperage currents of both narrow and wide electrodes; Pound and Cable, of Pye Radio, gave lectures on the fundamentals and on the application of radio-frequency methods.

External contributors provided all five papers in the engineering course. Giddings, of the Bristol Aeroplane Company, in "Design for Redux," told of his firm's investigations of this metal-to-metal adhesive for aircraft construction, and Parker spoke of the plant and methods needed for its application under factory conditions. Preiswerk, of Ciba, spoke of the ethoxyline resins, better known by the trade name "Araldite" and compared their properties with other casting synthetics.

Special adhesives employed in the electrical industry for bonding mica, ceramics, metals, rubber and laminated plastics were excellently described by Archer, of Metropolitan-Vickers, including their application to the 120-ton magnetic core of synchrotron. A highly specialised use for adhesives was given by Learmonth, of Gandy, namely, the bonding of friction fabrics to brakes and clutch plates. He spoke of both British and American techniques.

There is a comprehensive index, and the book is recommended both for study and reference purposes.

SYNTHETIC RESINS AND ALLIED PLASTICS. Edited by R. S. Monnell and H. M. Langton. Oxford University Press. 1951. 747 pp. with index. 87 Figs. 50s. net. (*Third Edition.*)

The chief fault of this book is in the title, for it would have been better called "The Chemistry of Synthetic Resins." It provides on the whole an excellent account of the chemistry and technology of resins and is indispensable to the resin chemist. The reviews of the constitution of phenolic resins (pp 132-138) are valuable, and so is the theory of resinification in Chapters 15 and 16. Shellac now has a chapter to itself (Chapter 14), but the discussion on silicones for the treatment of textiles and paper is misplaced (Chapter 10) as the conclusion to a chapter on Amino-resins for varnishes and enamels, and would be better included with the main discussion in Chapter 13. On a point of fact it is stated (on p. 33) that "The most needed improvement in silicone resins is the development of one which can be cured below 400°C," whereas these resins are normally cured in the range 150°-250°C.

Both examples of unsaturated polyester resins given on pp. 224-5 are now regarded as "early prototypes." Brief mention is made (pp. 369-370) of the polyurethenes, but the important

reaction between alkyds containing carboxyl groups and diisocyanates, which produces the expanded polyurethane foams, is not discussed. No account is given of the epoxy resins which have become so important since the war as metal adhesives.

A great weakness of the book, which renders it almost useless to the engineer, is that the description of the physical properties of plastics is very uneven and incomplete. While an attempt has been made to bring this new edition up to date by the addition of new resins and new chemical views, the mental approach remains that of ten or fifteen years ago. That is to say the authors are content to record that such and such a resin may be produced by reacting certain ingredients under given conditions, and to speculate about the chemistry of the process; concerning the engineering properties of the product they have apparently little curiosity. It is to be emphasised that what is needed is not so much new resins as reliable physical information about the very wide range of known resins.

It would have been better to have omitted any description of reinforced plastics than to have treated the subject so briefly and so badly.

The section on the manufacture of conventional small mouldings is fairly adequate; the inclusion of no less than twelve large illustrations of moulding presses seems rather extravagant. The new low-pressure methods for large mouldings are scarcely mentioned, although the polyester processes have been established in America for many years.

FUNDAMENTALS OF AUTOMATIC CONTROL. G. H. Farrington. Chapman & Hall. 1951. 285 pp. 30s. net.

Automatic control is of considerable interest to the aeronautical engineer be he concerned with design or production. In the last decade much progress has been made towards better understanding of the behaviour of automatic control systems and a considerable body of literature, much of it from the United States, is available on servo-mechanisms. In this literature considerable use is made of operational mathematics, particularly the Laplace transformations, and while this is a necessary and powerful tool in the hands of the mathematician it tends to mask the underlying physical principles. In " The Fundamentals of Automatic Control " the author uses the methods of classical mathematics although on occasion he has recourse to Heaviside's Unit Function and he keeps the physics well to the fore.

The treatment is mathematical but a reader of Higher National Certificate standard should experience no difficulty with it, since aspects which may not be familiar (except perhaps to electrical engineers) are given full treatment. Much use is made of electrical analogies in analysing the characteristics of hydraulic and pneumatic controllers.

The book is written in the language of Process Control using the terminology of B.S.Spec. 1523, Section 2 and there is only a passing reference to servo-mechanisms which the author states refer to Position Control—a very restrictive definition indeed! It is regrettable and confusing, but, of course, no fault of the author, that there is not a uniform terminology for process controllers and servo-mechanisms—dynamically similar systems having much in common; however, it is felt that the author of a book on "Fundamentals of Automatic Control" could have done good service in emphasising the common ground rather than coming down firmly on the side of process control. The reader will look in vain for any mention—by name—of Nyquist's stability criterion but very early on in the book he is introduced to this concept in its inverse form.

Despite these criticisms the book can be recommended to those who require a clear exposition on the subject of automatic control. It deals with principles rather than practice, although some examples are given in diagrammatic form of methods of achieving the desired control laws. Non-linearities receive scant treatment but this is to be expected since there is scope for a volume of comparable size on this subject alone.

SELECTED GOVERNMENT RESEARCH REPORTS, VOL. 5: SERVO-MECHANISMS. H.M.S.O. 1951. 293 pp. 63s. net.

This collection of 17 reports on research work done under the direction of the Ministry of Supply is published, according to the foreword, primarily for the benefit of British Industry.

Five of the reports are concerned with basic theory and analytical technique, and most of the remainder with various applications of servo-mechanisms.

The theoretical part of the book is a mixture of compression and expansion; while Operational Methods for Servo-Systems are covered in a single 21-page report, and the Interpretation and Use of the Nyquist Diagram occupies a dozen pages, no less than three reports totalling 49 pages are devoted to the relatively simple problem of extracting the roots of algebraic equations of high degree. This might be justifiable to some extent if a variety of methods were given, but they are all essentially the same, involving a systematic search for a quadratic factor.

Within the limits of two short reports, the accounts of the harmonic response diagram

and of Laplace transformation are clear and well-presented, although the obtaining of the correct initial values for the error derivatives is treated rather too superficially. An approximate method is given (somewhat diffidently) whereby the response of a system to a step input may be deduced from the experimentally determined Nyquist diagram, but since it depends upon a double graphical differentiation, it is unlikely to be very accurate.

The examples of servo-mechanisms in practice present nothing really new, as all the reports were originally issued between 1942 and 1947. Most of them are electronic; prominent among these are applications associated with radar tracking. The Velodyne is fully analysed, and a good description is given of an electro-mechanical Differential Analyser using Velodyne integrators.

The reviewer turned hopefully to the report dealing with " Tests on the ' Servodyne ' Hydraulic Flying Control Assister," but found this disappointing. The tests were made with an early model, using no feel-back, and no account is given of the effect on stability of varying the natural frequencies of input and output circuits.

The book is well produced, and misprints are few and trivial, but the general impression it gives is of a " take-it-or-leave-it " collection of information, which is not even arranged in any logical sequence. It is to be doubted whether British Industry will benefit significantly from this publication, and there is certainly little in it to justify its distinctly high price.

ADVANCED NATIONAL CERTIFICATE MATHEMATICS. J. Pedoe. English Universities Press Ltd., London 1952. 346 pp. Exercises and Answers. 15s. net.

It is not outside the realms of experience of the technical college student to be faced with proofs of theories in his engineering courses which require a form of notation or operation which will not be covered in the mathematics course until some later date. In order to avoid confusion in the mind of the student the lecturer is obliged to break the train of thought while he anticipates the work of his colleagues in the mathematics department. To what extent this state of affairs may be remedied by careful planning of the college syllabus is problematical, but the student can do much to help himself by making frequent reference to a good mathematical text.

Mr. Pedoe, as author, and Dr. W. E. Fisher as general editor of the Technical College Series of which " Advanced National Certificate Mathematics " forms a part, are to be congratulated on the production of a very readable text book which is intended as a help to the student preparing for the A.1 examination of the Higher National Certificate or the Part I examination of London University B.Sc.(Eng.). The reader is aided in his studies by the inclusion of revision chapters which form connecting links between earlier work and its extension in the pages following. The prospective B.Sc.(Eng.) may feel that this revision work has been undertaken at the expense of more detailed chapters on other topics, especially in view of the fact that the chapters on the straight line, circle and conic sections are in themselves little more than revision of his school work. The greatest failing in this respect is the rather clipped chapter on differential equations.

As evidence that the book is intended for engineering students, special chapters have been written on moments of inertia, centres of pressure, linear velocity and acceleration and equations of rotation; whenever possible, the worked examples and exercises have been given a practical aspect. Two other chapters are worthy of note; one on curve sketching and another on statistics. The latter deals with the arithmetic mean, standard deviation, histograms and frequency curves.

There are some eleven hundred exercises with answers and for the most part the book is well illustrated. Figures 8 and 9 are poor representations of the inverse sine and cosine functions and should be corrected in any future edition as attention to detail is very important when a student is being introduced to the fundamentals of his subject. The book lacks an index.

The technical college student should have no difficulty in keeping his mathematics up to the standard required in his engineering courses if he is prepared to pay the reasonable sum asked for Mr. Pedoe's book.

STRAIN GAUGES—THEORY AND APPLICATION. Professor Dr. Ir. J. J. Koch, *et al.* Philips Technical Library, Holland, 1952. Clever, Hume Press Ltd. London 1952. 95 pp. Illustrated. 15s. net.

Like a doctor with his stethoscope, so the structural engineer with his strain gauges can observe the condition of his patient at a number of points, and apply his remedies in good time. Thus the subject is of great importance in aeronautics, and the measurement of strain takes a wide variety of forms, but it should be made clear that this book deals only with the electrical wire resistance gauge, although mechanical, optical, and other electrical forms, indeed even the graduated scale, are not likely to disappear from our equipment. Within this narrow field however, this little book gathers together and presents economically the theory and more

particularly the " know-how " essential to anyone starting to use this technique; information till now only available in manufacturers' pamphlets and technical reports. There is no tendency to minimise the many errors and difficulties which will bedevil the user.

The text suffers slightly from being a translation and is sometimes difficult to follow; the same applies to the mathematical treatment where the symbols are insufficiently defined. Again the components described are too exclusively those of Philips, and the functioning of the electronic boxes is not sufficiently clearly explained for mechanical people not already familiar with radio circuit theory.

The advice that the surfaces used should always be roughened with a stone will not appeal to those dealing with fatigue; and is indeed not necessary; perhaps the authors' attention has been too much confined to civil engineering. Some interesting and novel " pick-ups " using strain gauges are described, and such instruments extend the field of application outside the purely structural.

This is perhaps the best book on the subject so far; the classic which will survive has yet to appear.

CARBURATION, VOLUME 2. Charles H. Fisher. Chapman & Hall, London, 1952. 279 pp. 124 Figs. Index. 36s. net.

This book can be regarded as complementary to the first volume, which was mainly theoretical, inasmuch as it is concerned with the functional, installational and servicing aspects of carburation as applied to road vehicles. The first section is devoted to a discussion on the various points to be considered when selecting and matching a carburettor to a particular engine. These include engine layout, the installed attitude of the carburettor, number of cylinders, firing order and maximum r.p.m.

An attempt is made to show how the size of the venturi choke can be established by calculation, but the author wisely observes that for best results this procedure should be supplemented by the "cut and try" method on test. In general, it is found that atomisation of the fuel is improved as the air speed through the choke is increased, other things being equal, but as this can only be obtained at the expense of increased pressure loss over the carburettor at full throttle with a consequent drop in power, there is an optimum value for the maximum air speed.

A figure of 400 ft./sec. is mentioned and presumably refers to road vehicles. For aircraft applications, it is usual to limit the ground-level choke velocity to a somewhat lower value than this on account of the amplifying action of the supercharger which can convert even a moderate pressure loss over the carburettor into the equivalent of a substantial reduction in the full throttle rated height. In the same section it is shown how road testing can assist in obtaining the best all-round performance and such characteristics as acceleration and idling are dealt with.

The largest proportion of the book contains a detailed and comprehensive description of the many types of carburettor encountered in this country and abroad, and it is pleasing to find an abundance of diagrams and photographs. The final chapter deals with the automatic control of the mixture for cold starting and describes several methods for achieving this.

As with the first volume, the standard of reproduction is very good and the publication makes a useful contribution to the field of carburation.

DESIGN OF MACHINE MEMBERS. Vallance and Doughtie. McGraw Hill Book Company, New York 1951. 500 pp. 51s. net. *Third Edition.*

This is a typical work on machine design, and covers the usual field in this subject very well. It is more of a reference book than one for a set course of study, but it contains much useful design data of a practical kind, presented in a pleasing way.

According to the Preface, the student is assumed to have had some training in kinematics, mechanics and factory processes. To judge by the pains to which the authors have gone in the first article in Chapter III to explain the meaning of tensile stress one would suppose that very little preliminary training was assumed, at least in mechanics. Yet in certain other parts of the book the customary amount of knowledge of calculus is assumed. It would have been an improvement if the various mathematical treatments that do appear had been more uniformly consistent.

Many text books fight shy of trying to explain to the student the nature of shear, and the present book is no exception. Great pains are taken to explain the meaning of such a simple conception as tensile stress, while the ideas of shear stress and shear strain are left to the student's imagination.

On pp. 52 and 53 the subject of complex stresses is dealt with. Here, as in the section on bending, the treatment could have been fuller. No mention is made of principal planes and principal stresses.

These minor criticisms, however, do not seriously detract from the value of the book as a whole.

After the introduction, the book starts with a good chapter on Engineering Materials. A good deal of useful data on Material Properties is given, although only for American specifications. Subsequent chapters deal with stresses in elementary machine members, with cylinders and pipes, shafts, riveted and welded joints, bearings, couplings and clutches, brakes, springs, wheel gearing, belt and rope drives, chain drives, etc., very clearly and well. A large number of exercises is given for the student to work out for himself, and many worked examples are provided in the text.

Although by no means an aircraft book, it is nevertheless well worth having in one's library.

AIR TRANSPORT IN AUSTRALIA. D. M. Hocking and C. P. Haddon Cave. Angus and Robertson Ltd. London 1952. 188 pp. Index. Appendix. 25s. net.

This is a book by two Lecturers in Economics of Melbourne University. It gives a broad economic and political account of the development of Civil Aviation in Australia; it does not set out to deal with the technical aspects of its subject, is factual and impersonal in its approach and not concerned with the personal problems, triumphs and failures of individuals.

Australian Civil Aviation deserves thorough study, for it occupies a place of great importance in the life of the Commonwealth and has reached a high level of efficiency; the internal air services have the lowest fare structure in the world and apparently not only cover total costs of operation but also manage to cover, through taxes, the cost of airports and route services: we would all like to know just how this is done.

The first part of the book deals with the historical development of civil aviation from the Larkin-Sopwith Company of 1918 up to the results achieved in 1950 by some 16 carriers, including the major operators, Trans-Australian Airlines, Qantas Empire Airways and Australian National Airways. If at times the book reads like abridged annual company reports it is perhaps indicative of the difficulty the authors have had in collecting more than elementary data on the operations they describe: for example, the bulk of the statistics in this part of the book are concerned with mileage flown and passenger miles performed (21 tables of mileage flown and traffic carried, two tables giving a summary of government subsidies, and three containing brief information on aircraft used). The device of graphical presentation is used sparingly, only one graph of passenger mileage, route mileage and tons of freight being given. In a work of this kind the reader's task is made a great deal easier by graphs giving perspective to the figures tabulated.

Policy and control are dealt with in the second part of the book. This makes fascinating reading and shows clearly the constitutional problems inherent in any attempt to co-ordinate air transport in Australia. The method chosen by the Labour Government in the Australian National Airlines Act of 1945 brought conflicts with the State Governments which had their lesser counterparts following the earlier Air Navigation Act of 1920, and led to somewhat oblique methods of achieving the desired results. The authors are careful not to pass judgment on these policies but seem to regret the difficulties in the way of applying the American solution of a Licensing Authority controlling development; this, they seem to think, would lead to more orderly and economical progress than the ruthless battle between Government and private enterprise which has, in fact, taken place. Be this as it may, they have an impressive achievement to describe and they do it well.

The achievements of A.N.A. and T.A.A. in providing cheap air transport have been so outstanding that one must regret that the authors have not been able to give more information on their organisation and costs of operation. Analysis of the relative efficiency and economy of equipment would likewise have been valuable. It is likely that in the absence of statutory obligation to publish cost figures on the internal services (such as there is in U.S.A.) no information was available; presumably the Q.E.A. figures have been supplied to I.C.A.O. in the standard form but these are not discussed.

In spite of this absence of more detailed economic analysis, the book gives a valuable account of Australian achievement and will undoubtedly become a standard reference for students of the development of Civil Aviation.

THE AIR LEAGUE AIRCRAFT RECOGNITION MANUAL. C. H. Gibbs-Smith. Putnam & Co. Ltd. 1952. 241 pages. Illustrated. 10s. 6d. net.

This book on aircraft recognition should be good. It is written by a prolific writer on the subject, assisted with facts and figures by Mr. Derek Thurgood of *Air Pictorial*, and illustrated by Mr. L. E. Bradford's excellent three-view silhouettes (already much appreciated as outline drawings in Jane's *All the World's Aircraft*) and by Mr. Charles Sargent's equally well-known aerocaricatures.

But for all these qualifications, the Manual is not what it might have been. The arrangement is too clever. The arbitrary allocation of aeroplanes into " large-fast," " large-slower," " medium-fast," " medium-slower " and " small-fast " and " small-slower " groups is not helpful. Such a breakdown only creates a complete hodge-podge of types in each category and adds confusion where the reverse is intended. A simpler arrangement with photographs, silhouettes, caricatures, " sillographs " and text on each aircraft type arranged together and in a more straightforward order would have greatly increased the book's value for reference.

Apart from the arrangement of material, the general layout is attractive. The photographs are good and for the most part well-chosen—although there are one or two unfortunate exceptions—and the other illustrations are well produced. The book as a whole is good value for the price.

The descriptive text is unusual. Mr. Gibbs-Smith has a style all his own in putting across the recognition characteristics of an aeroplane. To those who like his descriptive technique—and are familiar with his methods from the *Joint Services Recognition Journal*—the text of this book will certainly appeal. Others who, like this reviewer, are not attracted by the rather "precious" analogies used for many of the descriptions will find the text rather tedious.

TEDDER. Roderic Owen. Collins, London 1952. 320 pages. Index. 18s. net.

Biography has been defined as the art of presenting a life-work in full and significant delineation, but judged thus broadly Roderic Owen's careful study seems to fail, for the figure of Tedder is seen but mistily, the cloak of simplicity hiding his personality so that it renders his character baffling and leaves his thought unrevealed.

The difficulty of this portrayal is due to the diffident subject more than the author, yet Lord Tedder, Deputy Supreme Allied Commander, needs no panegyrist. Only a man of exceptional quality would have been picked among his contempories for so onerous and vitally important a career. Undoubtedly historians will regard him as one of the key figures of this age, so great was his influence on the use of Air Power.

Ostensibly masterman of the middle course, Tedder was neither upholder of a " blank cheque " all-out bombing policy nor the exclusive use of aircraft as ancillary to army or navy. He viewed the war as a combined offensive, on the part of all three Services, which might require a large share of the Allied Air Forces for any particular operation. That he and Eisenhower became a superb working combination arose from a unanimity of outlook that seems to have been sadly lacking elsewhere in the high command. Indeed, to the layman, it is ever disconcerting to discover, after the shouting is over, how deep was the conflict of policy among our professional leaders in the strategy and the technics of war, let alone the politics. Tedder, however, seems to have done more than most in securing Anglo-American co-operation in the field.

This biography perhaps over-stresses Tedder's pre-occupation in maintaining balance among conflicting requirements. " To tread the middle road so persistently might seem like walking a tight-rope. One might view such actions as being the antics of a well trained political acrobat if one knew nothing of the man's family, his upbringing and his past history. But Tedder's mind, though capable of acrobatic feats, had always been simple, his ideas direct, all else consciously or unconsciously, has been a disguise or a feint to baffle and disarm opposition." Undoubtedly he also possesses a subtle forcefulness in influencing instead of ordering other men's actions. Nevertheless, the Tedder of Mr. Owen's portrayal remains a man disguised.

THE WHITE RABBIT. The Story of Wing Commander F. F. E. Yeo-Thomas, G.C., M.C. Bruce Marshall. Evans Bros., London 1952. 262 pages. 16s. net.

One's first reaction after finishing this book is to wonder how any man could have survived such a succession of ordeals. The mere reading of the tortures and privations that Yeo-Thomas underwent at the hands of the Gestapo and other Germans is enough to make one feel sick and weak and yet he—no superman physically—not only endured but continued a personal campaign of propagandist patriotism that inspired others.

Yeo-Thomas was dropped in France to organise the flagging Resistance movement. His difficulties and the risks he ran are almost glossed over but eventually the Germans did manage to catch him and their elation gives one an idea of his influence. From here the story becomes almost incredible. The tale of suffering persists through the last 150 pages of the book but at no time did Yeo-Thomas desist from his determination to escape—a feat which he finally accomplished in time to celebrate VE day in Allied hands.

It is a pity, perhaps, that he did not tell his story himself. His biographer indulges too frequently in bitter parentheses and one feels that at times he is prejudiced somewhat unfairly, especially towards the R.A.F.

ADDITIONS TO THE LIBRARY

The following have been added to the Library. Books and papers marked with an asterisk may not be taken out on loan. The titles of pamphlets are printed in italics.

Ahrendt, W. R. and J. F. Taplin. Automatic Feedback Control. McGraw Hill. 1951.

American Society for Testing Materials. Symposium on Statistical Aspects of Fatigue. S.T.P.121. A.S.T.M. 1952.

American Society for Testing Materials. Symposium on Structural Sandwich Constructions. S.T.P.118. A.S.T.M. 1952.

Britton, S. C. Corrosion Resistance of Tin and Tin Alloys. Tin Research Institute. 1952.

Brock, G. C. Physical Aspects of Air Photography. Longmans Green. 1952.

de Haven, H. *Current Safety Considerations in the Design of Passenger Seats for Transport Aircraft. Crash Injury Research.* 1952.

Hall, A. R. Ballistics in the Seventeenth Century. C.U.P. 1952.

Hansen, H. M. and P. F. Chenea. Mechanics of Vibration. J. Wiley. 1952.

Hilton, W. F. High Speed Aerodynamics. Longmans Green. 1952.

Hoerner, S. F. Aerodynamic Drag. S. F. Hoerner. 1951.

*Parrish, W. W. (Editor). American Aviation Directory: Spring-Summer 1952. American Aviation. 1952.

Sherbrooke-Walker, R. Khaki and Blue. Saint Catherine Press Ltd. 1952.

*Siacci, F. Balistique Extéreure. Berger-Levrault. 1892.

Sokolnikoff, J. S. Tensor Analysis. John Wiley. 1951.

Tatham, R. Aeronautical Engineering Volume 2: Fundamentals of Aircraft Structural Analysis. English Universities Press. 1952.

U.S. Bureau of Ordnance. Handbook of Supersonic Aerodynamics. (Navord 1488 vol. 4.) U.S.G.P.O. 1952.

Williams, E. B. and W. J. V. Branch. Air Navigation: Theory and Practice. Pitman. 1952.

Aeronautical Research Council. Reports and Memoranda.

2409 *Bound and trailing vortices in the linearised theory of supersonic flow, and the downwash in the wake of a delta wing. A. Robinson and J. H. Hunter-Tod.*

2410 *The aerodynamic derivatives with respect to sideslip for a delta wing with small dihedral at zero incidence at supersonic speeds. A. Robinson and J. H. Hunter-Tod.*

2460 *Use of negative camber in the transonic speed range. W. F. Hilton.*

2469 *Experiments on thin turning vanes. C. Salter.*

2524 *Limitations of use of Busemann's second-order supersonic aerofoil theory. W. F. Hilton.*

2565 *Abstracts of papers published externally.*

2567 *Note on the effect of size of aircraft upon the difficulties involved in landing an aircraft. D. Adamson.*

2592 *The solution by lifting-line theory of problems involving discontinuities. V. M. Falkner.*

2594 *Calculated aerodynamic characteristics of two infinite wings with constant chord. V. M. Falkner.*

2596 *Calculated loadings due to incidence of a number of straight and swept-back wings. V. M. Falkner.*

2611 *The production of lift independently of incidence—the Thwaites flap, parts I and II. B. Thwaites.*

2612 *On the design of aerofoils for which the lift is independent of the incidence. B. Thwaites.*

2613 *Boundary-layer and wake investigation in supersonic flow. J. Lukasiewicz and J. K. Royle.*

2615 *The numerical method of characteristics for hyperbolic problems in three independent variables. C. K. Thornhill.*

2624 *Application of the linear perturbation theory of compressible flow about bodies of revolution. A. D. Young and S. Kirkby.*

2633 *Speeds and normal accelerations of Boeing Clipper aircraft on North and South Atlantic routes. D. T. Jones.*

2636 *Four- and eight-channel Desynn graphical recorders. F. R. J. Spearman.*

2673 *Note on the characteristic curve for an airscrew or helicopter. C. N. H. Lock.*

2705 *Systematic wind-tunnel tests with slats on a* 10 *per cent. thick symmetrical wing section (EQ* 1040 *profile). G. F. Moss.*

2772 *Forced flow against a rotating disc. Miss D. M. Hannah.*

The College of Aeronautics, Cranfield. Reports.

53 *An investigation of the noise field from a small jet and methods for its reduction. R. Westley and G. M. Lilley.*

54 *The potential due to a source moving through a compressible fluid and applications to some rotary derivatives of an aerofoil. R. Westley.*

56 *The determination in flight of the body drag and the mean blade profile drag coefficient of a helicopter. F. E. Bartholomew and W. S. D. Marshall.*

58 *Dynamic aeroelasticity of aircraft with swept wings. J. R. M. Radok.*

60 *An investigation of the flexure-torsion flutter characteristics of aerofoils in cascade. G. M. Lilley.*

61 *The theory of general instability of cylindrical shells. J. R. M. Radok.*

Aeronautical Research Laboratories, Australia. Reports.

SM.186 *Relative grain movements in aluminium with especial reference to surface phenomena. W. A. Rachinger.*

SM.187 *Strain ageing. A survey of the literature. F. G. Lewis.*

SM.189 *The activation energy for strain-age-embrittlement. C. J. Osborn.*

National Research Council of Canada. Reports.

AR-10 *Wind tunnel interference on rolling moment of a rotating wing. P. Mandl and J. R. Pounder.*

AR-11 *Wall interference in wind tunnels of closed rectangular section: development of equations. J. Sanders and J. R. Pounder.*

R.12 *Derivation and application of a general formula for directly computing the skin thickness of wings and tailplanes. A. H. Hall.*

R.14 *Spray nozzles for the simulation of cloud conditions in icing tests of jet engines. N. Golitzine, C. R. Sharp and L. G. Badham.*

Royal Canadian Air Force. Report.

950 *Two channel teletype equipment. A. W. Poushinsky.*

Institut Français du Transport Aërien. Research Papers.

215 *Future long-range jet flying boats. Probable effects on air traffic growth.*

216 *Simplified methods for the application of I.G.N. air navigation chart in gnomonic projection.*

221-222 *Draft flight manual adapted to proposed I.C.A.O. standards and recommended practices on aircraft performances.*

Publications Scientifiques et Techniques du Ministère de l'Air, France.

261 *Actes du colloque international de mécanique, Poitiers* 1950. *Tome IV. Etudes sur la mécanique des solides: études sur la mécanique générale.*

National Aeronautical Research Institute, Amsterdam. Reports.

F.88 *Pressure distribution calculations with viscosity corrections for aerofoils with flaps. J. A. Zaat.*

F.99 *Approximate theory of the oscillating wing in compressible subsonic flow for high frequencies. R. Timman.*

F.100 *Theory and practice of flutter calculations for systems with many degrees of freedom. A. I. Van de Vooren.*

S.402 *Theory and experiments on the elastic overall instability of flat sandwich plates. F. J. Plantema.*

V.1602 *An analysis of the pitching motion of an aeroplane due to sideslip. A. J. Marx and J. Buhrman.*

National Advisory Committee for Aeronautics, U.S.A.

Technical Notes.

2467 *The aerodynamic behavior of a harmonically oscillating finite sweptback wing in supersonic flow. Chieh-Chien Chang.*

2484 *Effects of compressibility on the flow past a two-dimensional bump. W. F. Lindsey and B. N. Daley.*

2489 *Aerodynamic characteristics of a refined deep-step planing-tail flying-boat hull with various forebody and afterbody shapes. J. M. Riebe and R. L. Naeseth.*

2496 *Flight investigation of a mechanical feel device in an irreversible elevator control system of a large airplane. B. P. Brown, R. G. Chilton and J. B. Whitten.*

2506 *An analytic determination of the flow behind a symmetrical curved shock in a uniform stream. C. C. Lin and S. F. Shen.*

2644 *Experimental investigation of an N.A.C.A.* 64A010 *airfoil section with* 41 *suction slots on each surface for control of laminar boundary layer. D. L. Burrows and M. A. Schwartzberg.*

2657 *Some effects of frequency on the contribution of a vertical tail to the free aerodynamic damping of a model oscillating in yaw. J. D. Bird, L. R. Fisher and Sadie M. Hubbard.*

2659 *A miniature electrical pressure gage utilising a stretched flat diaphragm. J. L. Patterson.*

2660 *An approach to the prediction of the frequency distribution of gust loads on airplanes in normal operations. H. Press.*

2663 *The gust and gust-load experience of a twin-engine low-altitude transport airplane in operation on a northern transcontinental route. H. Press and R. L. McDougal.*

2665 *An extension of lifting rotor theory to cover operation at large angles of attack and high inflow conditions. A. Gessow and A. D. Crim.*

2674 *Some experiments on visualisation of flow fields behind low-aspect-ratio wings by means of a tuft grid. J. D. Bird and D. R. Riley.*

2676 *Summary of stall-warning devices. J. A. Zalovcik.*

2677 *Wing-body interference at supersonic speeds with an application to combinations with rectangular wings. J. N. Nielsen and W. C. Pitts.*

2678 *Abnormal grain growth in S-816 alloy. A. I. Rush, J. W. Freeman and A. E. White.*

2679 *The stability under longitudinal compression of flat symmetric corrugated-core sandwich plates with simply supported loaded edges and simply supported or clamped unloaded edges. P. Seide.*

2682 *Transverse vibrations of hollow thin-walled cylindrical beams. B. Budiansky and and E. T. Kruszewski.*

2683 *Survey of portions of the chromium-cobalt-nickel-molybdenum quaternary system at* 1200°*C. S. P. Rideout and P. A. Beck.*

2684 *A low-speed investigation of a fuselage-side air inlet for use at transonic flight speeds. M. R. Nichols and E. B. Goral.*

2685 *A low-speed investigation of an annular transonic air inlet. M. R. Nichols and D. W. Rinkoski.*

2686 *Experimental investigation of heat transfer through laminar and turbulent boundary layers on a cooled flat plate at a Mach number of* 2.4. *E. G. Slack.*

2688 *Three-dimensional supersonic nozzles and inlets of arbitrary exit cross section. J. C. Evvard and S. H. Maslen.*

2690 *Condensation of air in supersonic wind tunnels and its effects on flow about models. C. F. Hansen and G. J. Nothwang.*

2691 *Theoretical and experimental analysis of one-dimensional compressible flow in a rotating radial-inlet impeller channel. S. Lieblein.*

2692 *On the form of the turbulent skin-friction law and its extension to compressible flows. C. du P. Donaldson.*

2693 *A theory and method for applying inteferometry to the measurement of certain two-dimensional gaseous density fields. W. L. Howes and D. R. Buchele.*

2696 *A fundamental study of the mechanism by which hydrogen enters metals during chemical and electrochemical processing. L. D. McGraw, C. A. Snavely, H. L. Moore, P. T. Woodberry and C. L. Faust.*

2697 *Method and graphs for the evaluation of air-induction systems. G. B. Brajnikoff.*

2700 *Reciprocity relations in aerodynamics. M. A. Heaslet and J. R. Spreiter.*

2701 *A survey of the aircraft-noise problem with special reference to its physical aspects. H. H. Hubbard.*

2703 *Electrical techniques for compensation of thermal time lag of thermocouples and resistance thermometer elements. C. E. Shepard and I. Warshawsky.*

2704 *Fatigue strengths of* 14S-T4 *aluminum alloy subjected to biaxial tensile stresses. J. Marin and W. P. Hughes.*

2728 *Experiments to determine neighborhood reactions to light airplanes with and without external noise reduction. F. S. Elwell.*

Technical Memoranda.

1317 *A simple numerical method for the calculation of the laminar boundary layer. K. Schröder.*

1331 *Investigations of the boundary-layer control on a full scale swept wing with air bled off from the turbojet. P. Rebuffet and Ph. Posson-Quinton.*

APPOINTMENTS

This page of the JOURNAL is available for advertisements of appointments in the Industry, the Ministries, Universities and Colleges. The charge for advertisements for each inch, or part of an inch, in depth is £2 10s. 0d.

TECHNICAL PUBLICATIONS MANAGER.—Applicants should have experience in the preparation of manuals and must also be familiar with A.R.B. and M.O.S. procedure. Please write, giving full details of experience, to Chief Designer, Dunlop Rubber Co. Ltd., Aviation Division, Foleshill, Coventry.

CHIEF STRESSMAN.—Applications are invited from senior stressmen with experience in pneumatic and hydraulic components. Knowledge of M.O.S. and A.R.B. design approval system is essential. Please write giving full details of qualifications and experience to Chief Designer, Dunlop Rubber Co. Ltd., Aviation Division, Foleshill, Coventry.

WELL-KNOWN INSTRUMENT manufacturers situated in West of England have a vacancy for a **Senior Project Engineer** to direct work of a team employed on design and development of a wide range of mechanical aircraft instruments and allied equipment. Applicants should possess qualifications in engineering and/or physics and previous experience in the design of pressure sensitive elements, small mechanisms and gears, together with a practical knowledge of metallurgy and general aircraft requirements. The post is pensionable and carries a salary of £900-£1,200, depending upon experience and qualifications. Housing assistance will be given. Write quoting reference 6/EN to: Personnel Manager, S. Smith & Sons (England) Ltd., Bishops Cleeve.

UNIVERSITY OF SOUTHAMPTON. Department of Aeronautical Engineering.—Applications are invited for the appointment of **Lecturer** or **Assistant Lecturer** tenable from 1st October 1952. Experience in the study of Aeroelasticity desirable. Salary scales—Lecturer £550×£50—£1,100; Assistant Lecturer £400×£50—£500, plus children's allowance and F.S.S.U. benefits. Further particulars may be obtained from The Secretary and Registrar, The University, Southampton.

GUIDED MISSILES.—The English Electric Company Ltd. have vacancies for:

(1) **Senior Stressman.** This post offers an opportunity to a well qualified man with initiative and the ability to supervise stressing calculations. A minimum of three years' experience on aircraft or missiles is essential and honours degree is desirable.

(2) **Stressmen.** Vacancies exist for both Senior and Junior Stressmen and while some aircraft or missile experience is desirable, consideration will be given to applicants with experience in other industries.

(3) **Graduate Engineers/Applied Mathematicians.** Honours graduates for advanced stress analysis investigations of a research nature are required. While aircraft or missile experience is an advantage, the primary qualifications are a good mathematical background and an enquiring outlook.

(4) **Aeroelasticians.** Technicians of degree standard are required for aeroelastic investigations. Previous work on aeroelastic problems is not essential, but past experience should include work on aerodynamics and/or aircraft structures, while a knowledge of supersonic aerodynamics is an added advantage.

(5) **Weight Control Engineers.** A vacancy exists for a Senior Weight Control Engineer capable of not merely calculating weight breakdowns, but of actively chasing and controlling weights. Some aircraft or missile experience is essential. There are also vacancies for Junior Weight Control Engineers to assist in this work.

All the above posts offer unique opportunities to the right men in an expanding organisation.

Please write, giving full details and quoting reference S.A.25, with appropriate number, to, Central Personnel Services, English Electric Company Ltd., 24-30 Gillingham Street, London, S.W.1.